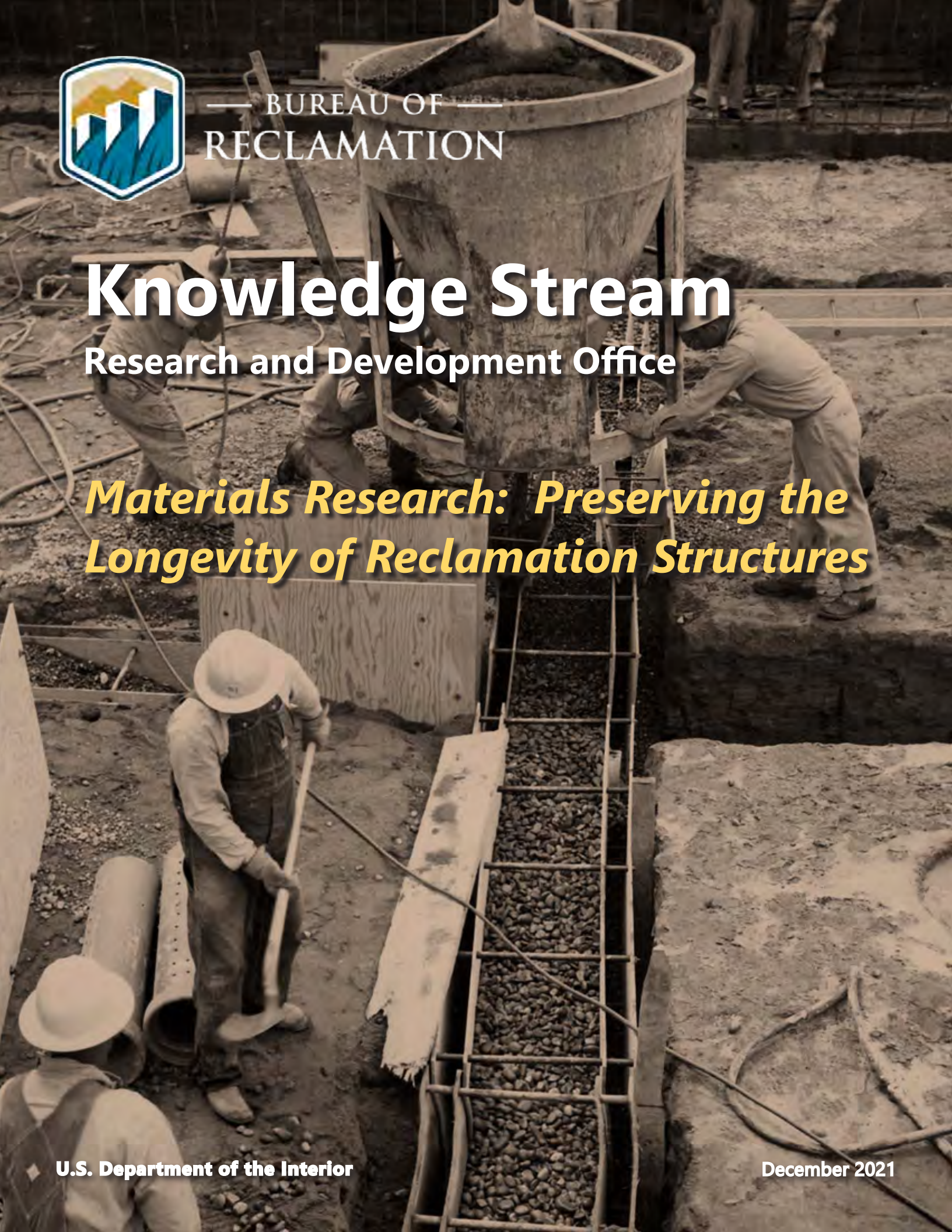

BUREAU OF RECLAMATION

Knowledge Stream

Research and Development Office

Materials Research: Preserving the Longevity of Reclamation Structures

U.S. Department of the Interior

December 2021

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Message from R&D

Welcome to the Winter 2021 issue of the Knowledge Stream! In this issue we highlight Research and Development (R&D) Office efforts in materials research to address the various challenges in our infrastructure. R&D has been funding research on materials to be able to meet the needs of our aging infrastructure and at the same time innovate and create the infrastructure for the next century. In this issue you will learn about the pioneering work of Reclamation scientists and engineers to make such advancements, including:

- Researching all aspects of concrete for construction and repair to increase life, performance, and sustainability
- Improving the communication and connectivity of the various data sources that provide information about Reclamation's infrastructure
- Prize competitions focused on challenges posed by materials such as for protecting steel from corrosion and for condition assessment of fiber reinforced polymer (FRP) composite
- Materials research on rock and soils to enhance our knowledge on unique properties and applicability to increase our understanding for repairs and improvements to our physical structures

In addition, you will also read about advancements in coatings, new rope materials, 3-D printing materials, and our strong partnership with the U.S. Army Corp of Engineers (USACE) Risk Management Center, and USACE Engineering Research and Development Center.

As always, we appreciate you reading about innovation and research funded by Reclamation's R&D programs. Please enjoy this issue of the Knowledge Stream. We welcome your feedback regarding research topics you would like to see highlighted in future issues or any ideas for improving our strategies to transfer solutions to users.

About the *Knowledge Stream*

The *Knowledge Stream*, published by the Bureau of Reclamation's Research and Development Office, is a quarterly magazine bringing mission-critical news about the agency's innovations in the following:

- Science and Technology Program
- Desalination and Water Research Purification Program
- Prize Competitions
- Open Water Data
- Technology Transfer...and more.

Content Lead

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usbr.gov/research

For more information on articles within this issue, please contact the listed author or Bobbi Jo Merten.

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Testing 3-D Printed Metal Parts

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Front Cover: Placing gravel for filter drains under floor slab on left abutment. Delta District, Central Valley Project. (L.R. Murphy, Photo. May 14, 1953.)

Back Cover: Riprap (large rocks and boulders) on the upstream face of Shasta Left Wing Dam.

The information being offered herein represents the opinion of the author(s) and is not a statement of fact about Bureau of Reclamation findings or conclusions.

Community Needs

Materials Research to Ensure Long-Lasting Structures

By Bobbi Jo Merten
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Materials research is the study of the constituents, i.e., the materials, used to build a structure, equipment, or other physical objects. The material types used at Reclamation are soil and rock, concrete, metals, and polymers. Each material has a unique set of properties, and scientists and engineers carefully select the best material for its intended use. Together, the materials result in physical structures that work together to convey water and produce power, helping Reclamation meet its mission to serve the Western United States.

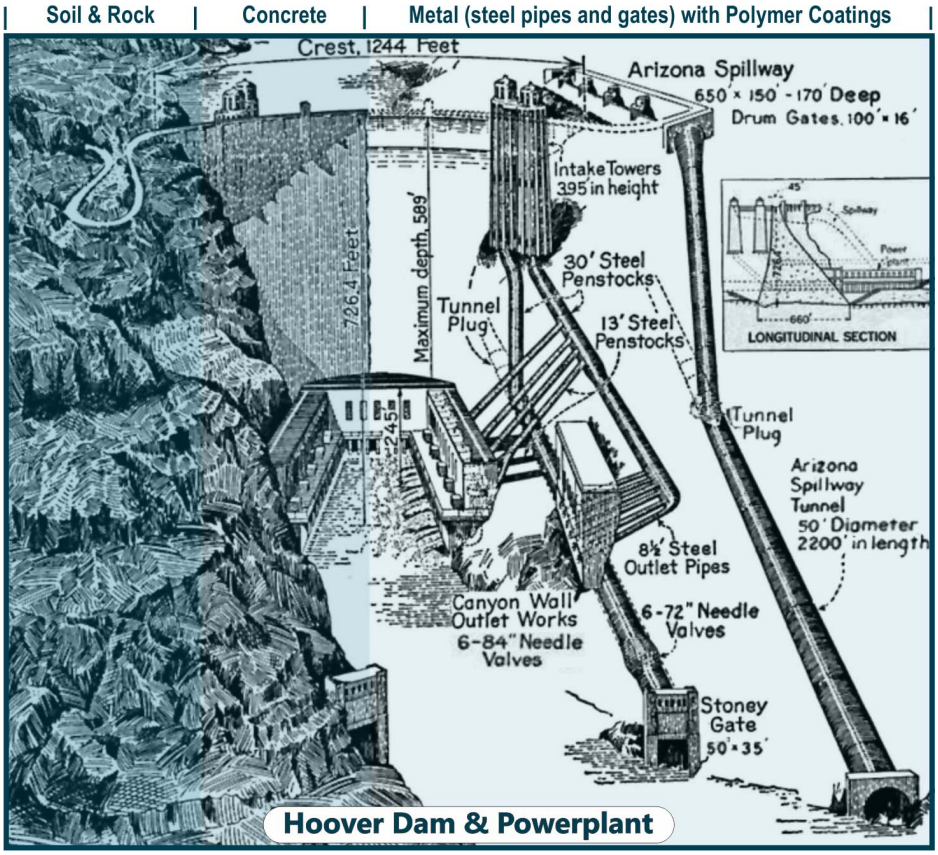

Diagram of a powerplant showing general locations of soil and rock, concrete, metals, and polymers. The left side of the image shows the facility exterior, and the right illustrates the interior components and equipment.

This issue of the Knowledge Stream explores the research being conducted on the material building blocks of Reclamation's physical infrastructure. The primary asset classes for these structures are dams, canals, pipelines, powerplants, and pumping plants, which are built from the ground up, starting with excavating and establishing a foundation. Each new stage of the construction process incorporates specific materials to meet the desired performance of the structure.

Reclamation has approximately 120 years of experience building and maintaining water infrastructure. The scientists and engineers that work at Reclamation have a thorough understanding of the materials used in these structures and know that materials selection is an engrained feature of building these structures. This experience informs decisions such as whether to construct an embankment or concrete dam, and the design data and material properties help determine which type of dam is most suitable for the existing geography and forthcoming reservoir. Materials selection also includes deciding which type of metal to use when designing gates and similar equipment and whether a canal lining, such as geosynthetic liners or concrete panels, is needed to slow seepage.

Reclamation's expertise continues to grow as new tools for evaluating our structures and better materials become available. The developments are timely, as climate change is deepening the challenge for Reclamation to achieve its mission. Extreme droughts and flooding create difficult conditions through which a structure must continue to function. Materials research ensures that persistent and evolving needs are identified and addressed. See the Key Perspectives article, "Studying the Building Blocks of Reclamation Structures," for an indepth look.

Concrete Roads to Roadmaps

By Barbara Aguilera-Gonzalez & Katie Bartojay
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www.usbr.gov/tsc/tscorganization/equipment/8530equipment.html

Reclamation has been essential to the expansion, settling, and infrastructure growth in the West since its inception in 1902. Most construction was completed in the 1930s, with the last major new construction project occurring in the late 1960s. Concrete has been integral in many of Reclamation's structures, and it will continue to be a major component for construction and repair.

Research roadmapping helps identify where to best focus research efforts to meet Reclamation's mission. Past research on concrete focused on the materials that make up this precious building composite. Looking ahead, future research will include reviewing all aspects of concrete for construction—processes, sequencing, proportioning, new materials, and sustainability, with the goal of increasing the performance and longevity of future batches of concrete.

The Concrete and Structural Laboratory in the Technical Service Center (TSC) in Denver, Colorado, is leading the development of a Concrete Research Roadmap. The objective is to further Reclamation's knowledge of the concrete research areas and to prioritize research pursuits as they relate to the mission of Reclamation: water and power delivery.

The goal of this roadmap is to get collective feedback from colleagues in the regions who are most familiar with the concrete-related issues and challenges facing Reclamation structures now and in the future. This feedback will result in a strategy to advance concrete materials engineering practice for aging water storage and conveyance infrastructure as well as new infrastructure. The concrete research topic areas to be investigated include concrete materials (aggregate, cementitious, admixtures), material properties (strength, durability, thermal properties), deterioration, repair maintenance, and life cycle analyses.

The roadmapping process will begin in early 2022 with a survey of Reclamation area offices, partners, and stakeholders to identify Reclamation's concrete research needs. The roadmapping team will then analyze and compile this feedback into a comprehensive report to guide future research and address the research needs statements and questions in the survey. The roadmapping process will also identify supporters, partners, and champions for future research. To learn more, or to participate in the survey, contact Katie Bartojay, Manager of the Concrete and Structural Laboratory.

Enterprise Asset Registry

By Dan Staton & Nick Casamatta
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The size and quantity of Reclamation's infrastructure is massive: over 500 dams, 140 million acre-feet of reservoir storage, 78 hydropower facilities, and over 8,000 miles of canals. Common details about the infrastructure portfolio are sometimes isolated in separate data sources, resulting in duplicative or conflicting information. Connecting these data sources will help to more efficiently manage Reclamation assets. For example, if a material defect is revealed by industry for a certain type of pipe manufactured in the 1960s, how do we know if Reclamation has any in the inventory? If a wildfire is approaching a Reclamation Project, how do we quickly identify and then communicate what assets could be impacted? If significant deterioration is identified at an asset due to environmental conditions, how do we identify other assets that may be susceptible?

Historically, Reclamation has used specialized but isolated asset inventories to answer these questions. Different offices managed separate inventories, and there was no single, verified source that area offices, regions, Denver Offices, or the Washington Office could point to for foundational asset information. The goal of the Enterprise Asset Registry is to establish an authoritative source for asset information.

The Enterprise Asset Registry is a 3-year project that will establish the asset inventory for all of Reclamation's high-level assets. The asset registry is broken down into 18 individual asset classes, including dams, pumping plants, conveyance lines, transportation, recreation, etc.

The project involves developing data requirements for each asset class, establishing an initial inventory, having local area/field office experts verify the inventory, and maintaining the inventory into the future.

In fiscal year 2021, the dams, urban canals, and reservoirs asset classes were completed. The hydropower facilities will be completed next, in December 2021. All completed asset classes can be found in Tessel, and a summary of asset class information can be found in the asset class dashboards for dams, urban canals, and reservoirs.

Once the Enterprise Asset Registry is established, Reclamation will be able to link the foundational asset data to other systems, such as recommendation management, inspection scheduling, and maintenance management, without duplicating data or introducing potential data conflicts. The Reclamation community, from field offices to materials researchers, is now able to use these resources through Tessel, dashboards, or by downloading asset data to Excel.

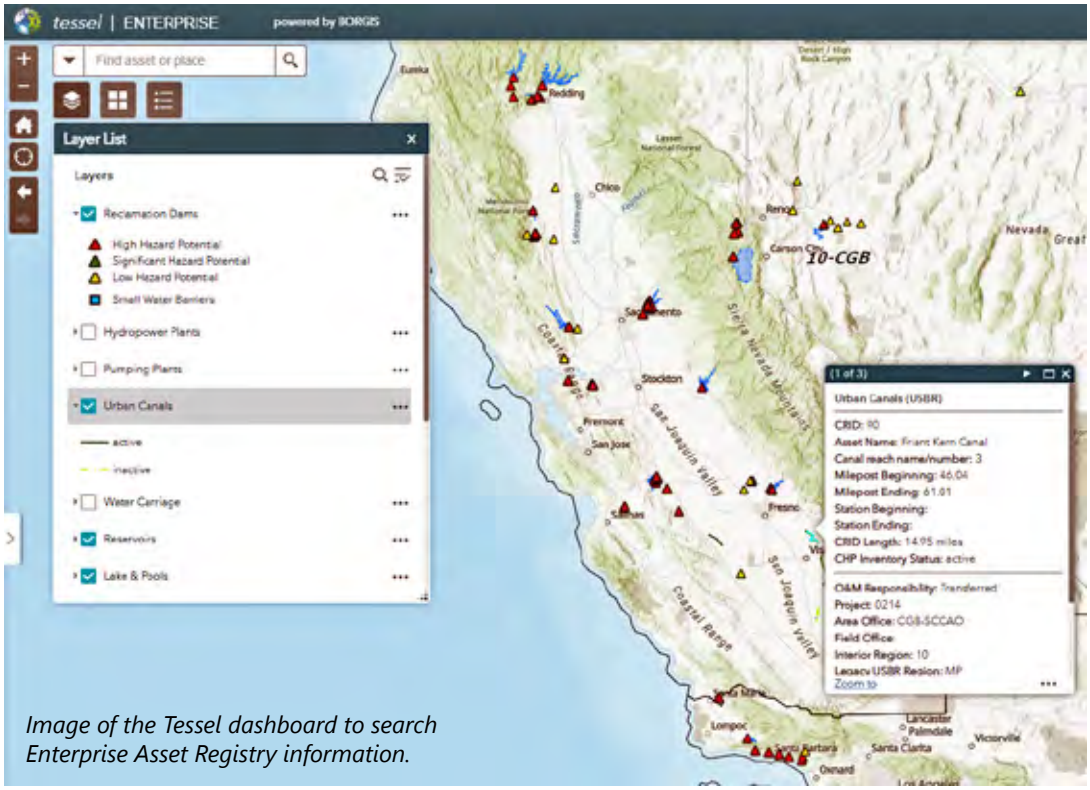

Image of the Tessel dashboard to search Enterprise Asset Registry information.

Dam Safety Technology Development Research

By Katie Bartojay, Kent Walker, & Lisa Krosley
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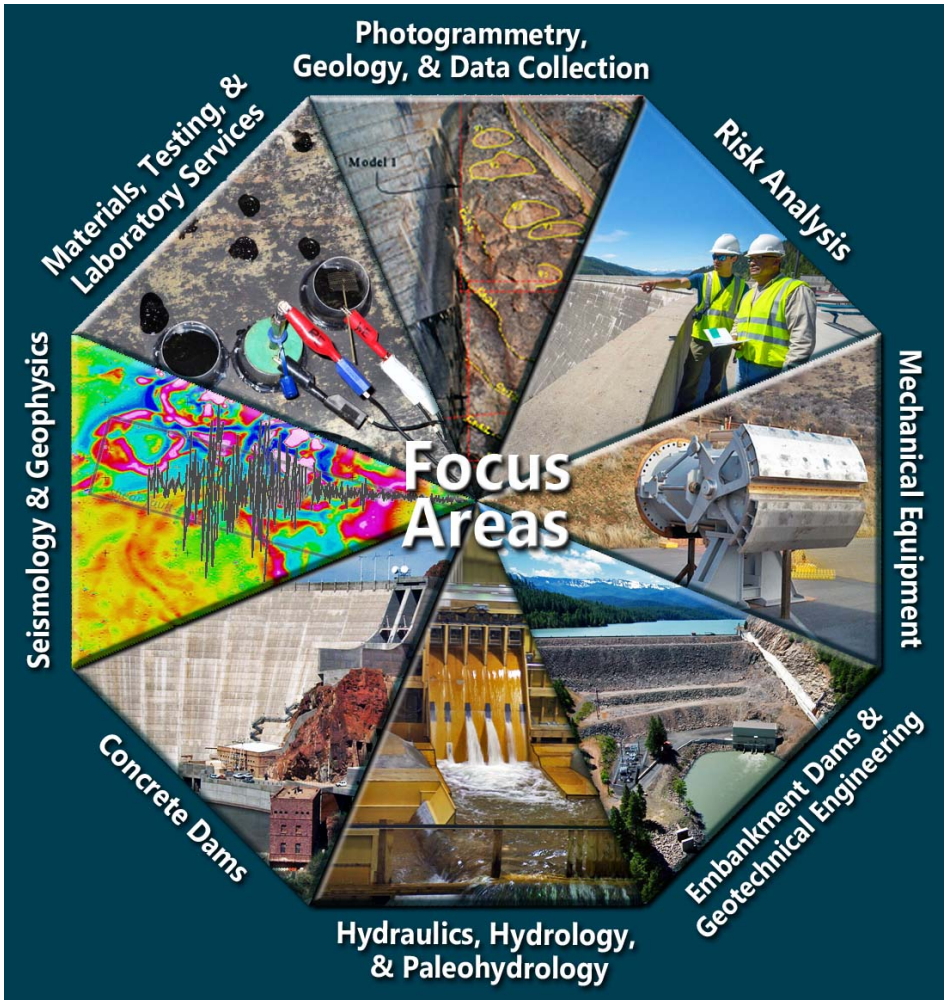
Dams must be operated and maintained in a safe manner. The Reclamation Dam Safety Office, through its many programs, focuses on safeguarding the public, property, and the environment. Reclamation's inventory of high-hazard and significant-hazard dams are continuously monitored and reviewed on a reoccurring basis. Identified issues are investigated to better understand the risk. The Dam Safety Technology Development (TechDev) Program was created to increase the knowledge base in areas that affect embankment and concrete dams, resulting in a better understanding of challenging engineering issues.



Dam Safety Technology Development.

A Dam Safety TechDev Advisory Panel, made up of seven Reclamation technical experts, meets annually to set yearly priorities based on experience from dam-specific risk analyses, issue evaluations, and corrective actions studies, and to transfer knowledge from collaborative committee work within the U.S. Society on Dams, Association of State Dam Safety Officials, and International Commission on Large Dams. The annual call for proposals is typically in September, and Reclamation principal investigators are encouraged to seek partners within Reclamation and from other government agencies.

The Dam Safety TechDev Program mainly focuses on applied science with a research-based approach to help improve the tools used during dam analyses or the collection of data. TechDev projects may also be co-funded by the Science and Technology Program when appropriate. From a materials perspective, some recent key priorities included understanding material properties of concrete structures, studying causes and methods to mitigate deterioration, modeling the strength of foundation materials, and improving methods and guidelines for characterizing the liquefaction potential of soil foundations.

Research projects can be primarily related to Safety Evaluation of Existing Dams for Reclamation's larger dams, or they can have a broader influence with a direct benefit to other smaller dams within the Department of the Interior that are owned or operated by the National Park Service, Bureau of Indian Affairs, or U.S. Fish and Wildlife Service. For more information, please contact Lisa Krosley, Dam Safety Office, Program Coordinator.

Prize Competitions Improving Reclamation Materials

By Bobbi Jo Merten
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www.usbr.gov/research/challenges/index.html

Reclamation sponsors prize competitions to help advance research on persistent and emerging challenges. The approach supports traditional research efforts by engaging the broader scientific community. Participants are rewarded with cash prizes and other non-monetary prizes or recognitions. These competitions help spur innovation and advance the state of the science. The objective is to advance successful solutions found in these competitions to facilitate implementation at Reclamation. Two materials research competitions underway are Rust Busters and Imperfection Detection.

Reclamation staff lowering Rust Busters prototypes for testing at Parker Dam, California.

The Rust Busters prize competition builds on to the completed Long-Term Corrosion Protection of Existing Hydraulic Steel Structures prize competition. The competition seeks new materials or methods to protect steel structures from corrosion. In March 2020 the Rust Busters competition advanced five finalists to prototype development for field and laboratory evaluations.

Rust Busters field testing began in July 2021 with installation of four field-ready prototypes at Parker Dam, California, in the Lake Havasu reservoir. These prototypes will remain in the field to test their corrosion resistance and will be evaluated on their performance. Reclamation's Materials and Corrosion Laboratory Group tested the five solutions for corrosion protection performance in the lab and awarded the Best Laboratory Performer in December 2021 to a novel robotic spray application technology for coal tar enamel.

Imperfection Detection prize competition logo showing a non-destructive tool being used on a pipe.

The Imperfection Detection: Detect Me If You Can prize competition seeks innovation in assessing the condition of infrastructure made from fiber reinforced polymer (FRP) composite materials. FRP composite materials are emerging as an attractive alternative to steel and are seeing increased use.

Field tools are needed to ensure that deterioration or imperfections unique to these materials can be detected before causing failure of a structure. Phase 1 of the competition is complete. Five winners advanced to Phase 2 and are developing a prototype for demonstration. Up to three finalists will be selected to compete in the Phase 3 final demonstration in fall 2022.

Partnering on Materials Research with the U.S. Army Corps of Engineers

By Bobbi Jo Merten
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Partnerships offer many advantages to the organizations and participants involved. Reclamation engages in research partnerships to share funding, spread results to a wider audience, reduce duplication of work efforts, and transfer knowledge. These benefits are realized through many partners across the organization. In FY22, Reclamation Science & Technology Program researchers and USACE ERDC coordinated on 28 funded projects, with Reclamation funding $2.54 million and the USACE in-kind or cash partnership valued at $3.78 million, including $2.65 million for one project. This article highlights materials research partnerships with the U.S. Army Corps of Engineers (USACE).

Materials research ensures that physical structures are durable and long lasting. The USACE manages and maintains similar water infrastructure to Reclamation, making them an important partner in many Reclamation materials research projects.

The USACE Risk Management Center (RMC) in Lakewood, Colorado, works closely with Reclamation on topics such as internal erosion of embankment dams and canals. The RMC specializes in risk analysis, which is also critical to Reclamation. Both agencies work together to better understand the behavior of the materials in these structures to support decisions.

The USACE Engineering Research and Development Center (ERDC) broadly addresses challenging research for both civil works and the military. Reclamation partners with the ERDC through the Collaborative Research Team Charter, established in 2014. The charter facilitates research collaboration in infrastructure sustainability, ecohydraulics and sedimentation, invasive species, and forecasting and reservoir operations. The ERDC laboratories in Champaign, Illinois, and Vicksburg, Mississippi, provide much of the organization's materials research. Reclamation coatings, corrosion, and concrete researchers, for example, work closely with their respective counterparts in these locations.

Annual meeting of collaborative research team charter; photo taken in December 2019, at the ERDC in Vicksburg, Mississippi.

Key Perspectives

Studying the Building Blocks of Reclamation Structures

By Katie Bartojay, Robert Rinehart, Dave Tordonato, Jessica Torrey, & Alan McCann
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During the Hoover Dam era, Reclamation led the charge in the development of new materials and new testing procedures to evaluate construction materials. As we continue to move into the future, some of these practices still hold true, while others need to be reevaluated using our knowledge of newer materials in the context of sustainability.

Reclamation uses several material types to construct dams, powerplants, canals, pipelines, and associated structures. The following figure describes the four different material types, noting the unique characteristics for each as well as the applications across Reclamation. As the importance of "infrastructure" makes its way into every household, these materials lay the groundwork for modernizing our physical structures.

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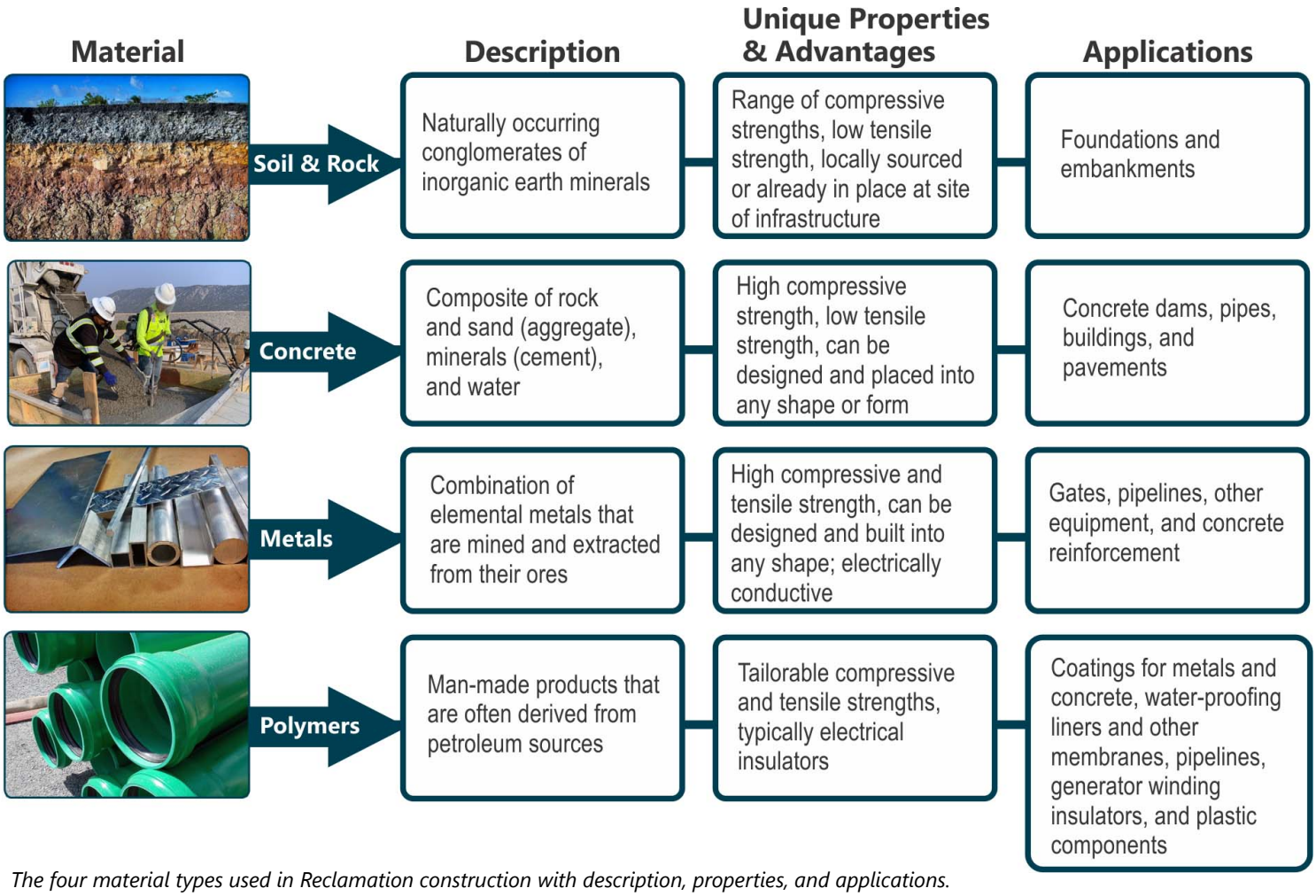

The four material types used in Reclamation construction with description, properties, and applications.

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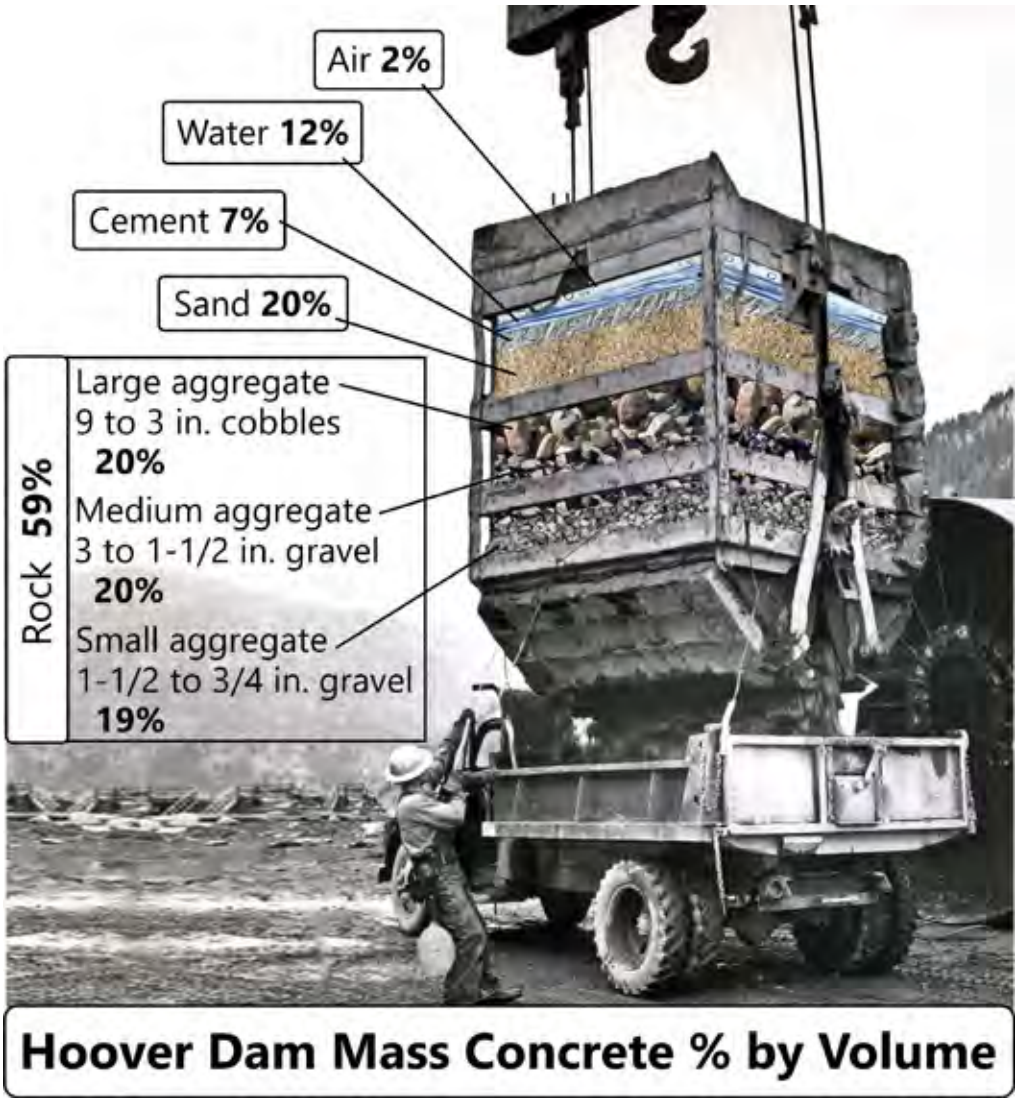
Materials research enhances our knowledge of these materials. Most Reclamation structures are already in place. Here, the research goal is to ensure reliable structures and optimized maintenance practices. An example is material degradation studies. This research helps Reclamation's asset managers understand how their structures are changing over time. Examples of materials degradation research include alkali-silica reaction in concrete, internal erosion of earthen embankments, and corrosion of steel pipes.



Historic photo of concrete truck from Reclamation's Hungry Horse project demonstrating the composition of concrete used at one of Reclamation's most historic projects, the Hoover Dam.

Structure repair also benefits from materials research. In this case, the research helps to identify when repair is needed and the best repair materials. It also determines how to prepare existing structure surfaces for the repairs, such as by studying how the old and new materials work together. The general goal is to find the longest-lasting repair at a low cost.

Likewise, new construction by Reclamation requires materials research to test new materials as alternates or replacements to traditional materials. In some cases, the new materials provide advancements to the traditional materials and practices, and in other cases, the new materials are needed to respond to regulations, supply, or similar changes in circumstance.

Subject matter experts weigh in on important materials research in the sections that follow. The discussions on each of the four materials classes help to shed light on the importance of each material. Further, the sections reveal the focal points of ongoing or future research.

Soil and Rock

The Earth's crust is primarily composed of inorganic mineral materials—simply put, soil and rock. The entirety of Reclamation's infrastructure (and for that matter the world's infrastructure) rests on the Earth's crust. Our roadways, buildings, dams, and canals all rely on a foundation of soil and rock. Further, Reclamation's embankment dams and canals are made from soil and rock. Dealing with these natural materials, in contrast to man-made materials such as concrete, metal, or plastic, presents many challenges. For example, soil and rock have complex responses to static and dynamic loads and present a high degree of spatial variability.

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In most cases, soil and rock do not necessarily change or degrade significantly over time; however, our understanding of the loadings that Reclamation infrastructure is subjected to has evolved. We now understand earthquake shaking and flood loading in much more indepth ways. Climate change is also affecting the hydraulic loading our structures experience. Research can help us understand how soil and rock materials respond to these better understood loadings. One example is studying soil liquefaction—where soils lose all strength and behave as a liquid due to cyclic loading from an earthquake. This phenomenon is becoming well understood for primarily sandy soils; however, it is not yet well understood for gravel soils or clay soils. Another important area of research is looking at how soil materials erode due to flowing water, both externally (like scour of a riverbank) and internally (like piping under an embankment). Other research is focused on developing numerical modeling and 3D visualization techniques that allow engineers to better quantify and understand spatial variability in soil and rock structures and foundations.

Concrete

Concrete, most simply, is a conglomerate of cement, rock, sand, and water. Rock and sand make up the largest proportion, and the cement and water react to bind the components together. Chemical admixtures and other supplementary powders and fillers can enhance the performance of this rudimentary material. These enhancements make it possible to hold back water with our dams, raise skyscrapers, provide blast protection, or absorb CO_2.

Reclamation uses concrete in our canals, dams, pipelines, powerplants, bridges, and buildings. Concrete testing and research help to design concrete mixes for these structures that are economical and long lasting. Durability is also critical when dealing with environmental factors such as chemical attack from aggressive soils and rocks or freezing and thawing in our cold weather projects.

Concrete designs often rely on old techniques and materials used in the past. Current research is modernizing the toolset to repair old concrete by evaluating new supplementary or alternative cementitious materials, including natural pozzolans (natural ash or calcine deposits). Recycling and reusing demolished concrete to make new concrete structures is also under investigation.

Metals

Metals are a class of engineering materials commonly used in many applications of modern society from bridges to airplanes to power transmission lines. Metal components can be cast, forged, formed, welded, and/or fastened together to create a part. At Reclamation, metals are used frequently across the water infrastructure inventory. Typical uses include penstocks, piping, turbines, pumps, valves, gates, trashracks, heat exchangers, screens, concrete reinforcement, electrical wiring, and many other types of components.

Metals are vital in infrastructure because they offer much flexibility in the variety of ways that parts can be created; they can be designed for loading in tension (pulling), compression (squeezing), and other configurations. Metals can be repaired, recycled (melted down and reused), and combined to create special alloys with desired properties. Metals are also electrically conductive, making them key materials in hydropower generation and transmission.

Steel is the most common alloy in use for hydraulic infrastructure, but it can corrode (rust) over time when exposed to moisture. Research at Reclamation is focused on protecting metals such as steel from corrosion, developing new ways to inspect and repair metals in the field, and creating new fabrication techniques such as additive manufacturing (aka 3D printing). Other metals used at Reclamation include stainless steel, aluminum, and copper.

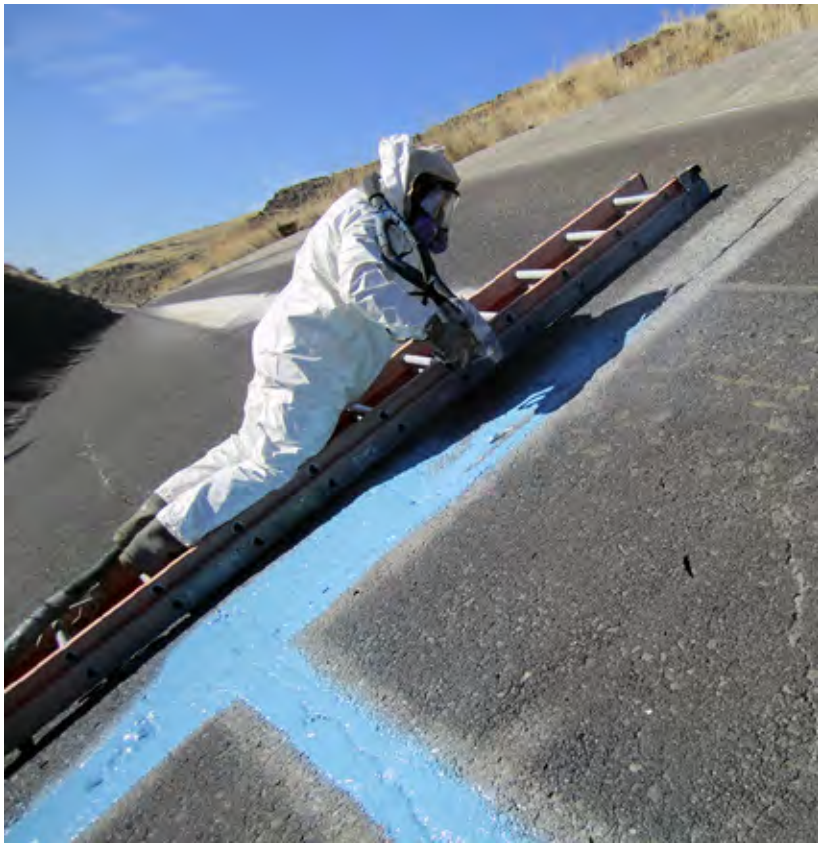
Polymers

Polymers are comprised of large molecules and can be synthetic (man-made) or naturally occurring. Polymers are a mainstay of modern life and include the plastic and rubber compounds found in many consumer products. They are also an important class of materials at Reclamation and are used in coating resins, geomembranes, piping, generator insulation, electrical wire sheathing, and repair materials. The material properties of polymers, such as strength and elasticity, can be tailored for the specific application.

Fiberglass reinforced polymer (FRP) composite pipe at field installation site.

Coatings are the most common means to prevent corrosion on steel structures. Research at Reclamation has included testing of novel and commercial coating systems for long-term corrosion control and special applications such as preventing fouling from invasive species, i.e., zebra and quagga mussels. Geomembranes may be used as waterstop materials in dams, drainage systems, erosion control, lining materials for ponds and canals, roofing membranes, and other applications. These materials must meet the strength, durability, and other property requirements to ensure a long service life.

Polymer pipe can reduce life cycle costs, when compared to steel, by reducing the expenses associated with corrosion control. Depending on the operating pressures, volumes, etc., a plastic pipe such as high-density polyethylene (HDPE) may be selected. A fiber-reinforced polymer (FRP) "composite" pipe such as fiberglass may be used for higher pressures. FRP materials are also sometimes used to repair damaged surfaces of steel or concrete structures in the field. Reclamation is funding a prize competition to identify new inspection methods for FRP composite infrastructure—see earlier article in this issue, "Prize Competitions Improving Reclamation Materials."



Elastomeric polymer coating being applied as a crack sealant for concrete panels to reduce canal leakage.

Dust-Reducing Materials

Dust-Reducing Materials at the Salton Sea

By Angel Gutierrez & John Fleming; Partner: Edward Kavazanjian (Arizona State University)
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S&T Project page: www.usbr.gov/research/projects/detail.cfm?id=21016

Reclamation's Yuma Area Office is partnering with the Imperial Irrigation District and the Center for Bio-mediated and Bio-inspired Geotechnics (CBBG) at Arizona State University to investigate approaches for reducing dust generated by the Salton Sea. The Salton Sea is a shrinking, man-made, highly saline body of water in southern California that represents the largest, and perhaps one of the most polluted, lakes in the State. Approximately 90,000 acres of land under and adjacent to the Salton Sea is owned and managed by Reclamation.

The Salton Sea formed in 1905 when a breached Imperial Valley irrigation canal inundated the Salton Sink with Colorado River flood waters. For more than a century, agricultural return flows sustained lake levels, but prolonged drought conditions and

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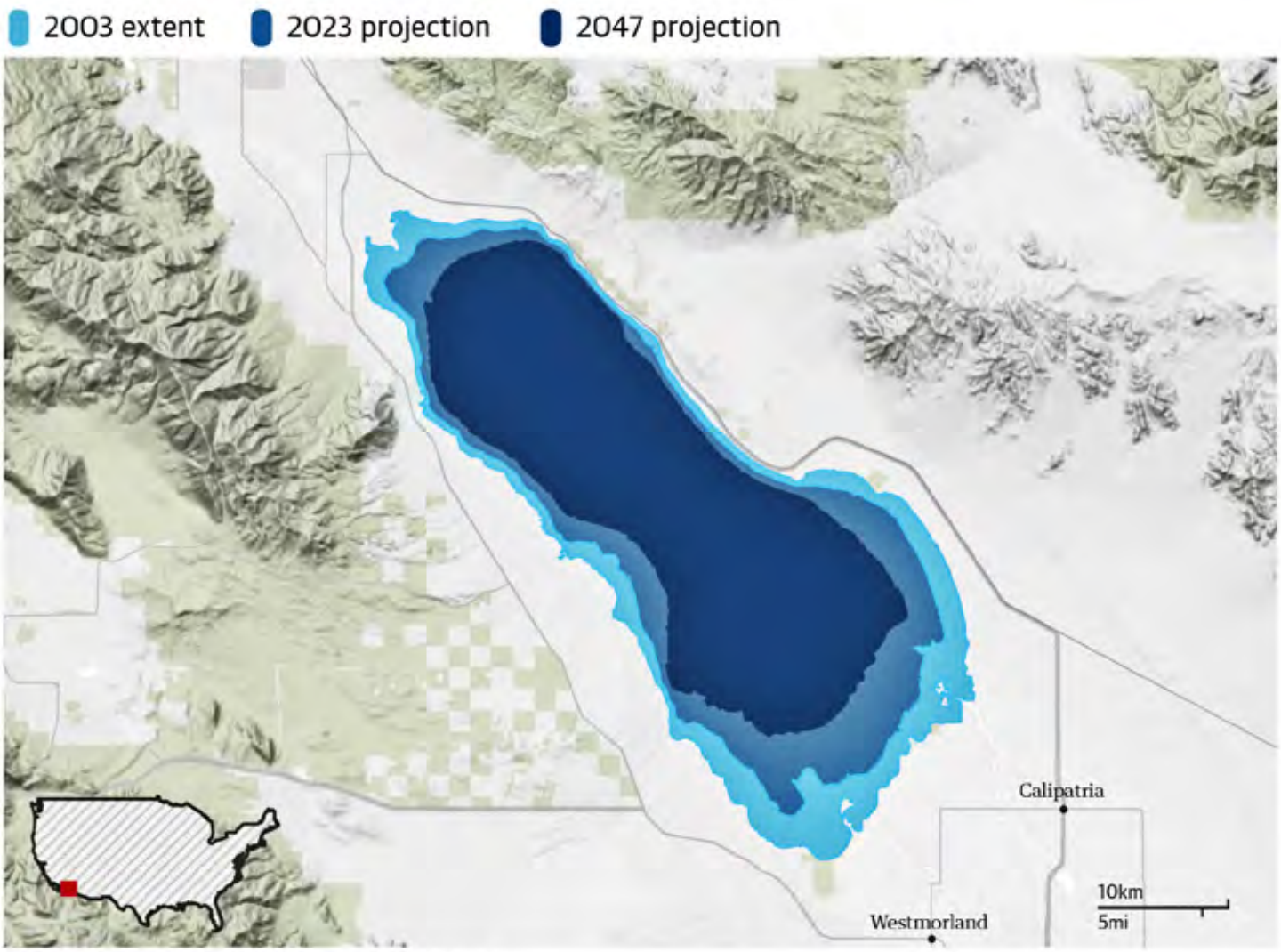

Guardian graphic. Source: Audubon California

Salton Sea Shorelines, 2003 – 2047 (projected). (Image retrieved from ca.audobon.org)

Dust storm in the Salton Sea obscures vision and produces a health hazard. (Photo by USGS/Milt Friend)

Dust storm covers Chandler, Arizona on August 11, 2011. A new study shows an uptick in Southwestern dust storms spurred by rising sea temperatures. (Photo by NOAA/NWS/Christopher Scragg)

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reductions in runoff due to conservation efforts are forcing the lake to shrink. As lake levels recede, the resulting exposed playa contains sediments laden with agricultural byproducts (fertilizer and pesticides). Dust storms, which are common in the area, transport substantial amounts of contaminated dust downwind where residents in the Imperial Valley are now experiencing often severe respiratory ailments. Reclamation, the Imperial Irrigation District, and the California Department of Water Resources have been tasked with trying to find a solution to help reduce this fugitive dust.

Biogeotechnical carbonate precipitation is among the methods being explored by Reclamation and its partners to mitigate fugitive dust from the playa sediments as the Salton Sea shrinks and the playa expands. The CBBG is developing this new, innovative approach to dust control in which a natural calcium carbonate, or calcite, cement is precipitated to form a dust-resistant soil crust. Both laboratory and field studies are being used to evaluate the efficacy of this technique to reduce dust from the exposed Salton Sea sediments. Two ways to form this calcite crust will be investigated. One method, referred to as microbially induced carbonate precipitation (MICP), relies upon naturally occurring microbes to induce calcite precipitation. The other technique, enzyme induced carbonate precipitation (EICP), uses enzymes extracted from a relative of common soybeans instead of the naturally occurring microbes.

The research will first evaluate crust formation in the laboratory, adjusting the formulation of each method to create a durable crust on top of the sediments. This laboratory testing is currently underway and includes a comprehensive characterization of the sediment composition followed by an assessment of the susceptibility to dust generation of laboratory-created crust. Dust generation is evaluated using wind tunnel testing and a specialized portable device capable of measuring dust mobilization both in the laboratory and in the field.

The project will next demonstrate the ability of these technologies to control dust at the field scale. The field-scale testing will entail treatment of two 1,000 square meter plots: one with EICP and one with MICP. These plots will be monitored for dust generation and crust durability and will be compared to a control (no treatment) plot.

The project will also complete a life-cycle analysis of dust mitigation technologies to quantify and compare the environmental and economic impacts of both biogeotechnical methods with existing dust control methods. The completed project will provide a comprehensive evaluation of these innovative biogeotechnical methods to provide durable, cost-effective mitigation of fugitive dust and the associated impacts to human health and the environment.

Concrete Materials

Improving Flow on Concrete Surfaces of Water Structures

By Josh Mortensen, Katie Bartojay, & Catherine Lucero (TSC's Structural & Concrete Laboratory);
Partners: Alba Valeria Canellas (Brazilian Agency FURNAS), and Marcelo Marques (Federal University of Rio Grande do Sul, Brazil)
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S&T Project page: www.usbr.gov/research/projects/detail.cfm?id=21051

Cavitation and erosion damage to spillways and stilling basins are a problem for both the Brazilian Government and Reclamation, and each have made costly repairs that impact operations. Reclamation's typical approach to cavitation is to first mitigate the source by adjusting geometry, aeration slots, etc. The follow-on is to line the structure with steel, high-strength concrete, or other durable materials in locations where mitigation through design is not possible. However, there is no clear guidance for engineers and designers for selecting concrete strength parameters for repairs or new designs. Specialized materials and construction techniques are needed when concrete strengths go above about 8,000 psi, but selecting an unnecessarily high value can significantly increase repair and construction costs.

The main objective of this study is to develop a reliable correlation between concrete properties and local hydraulic conditions. This enables design engineers to choose the most cost-effective concrete design for the application. Reclamation began collaborating in 2018 with materials and hydraulics laboratories at FURNAS of the Brazilian Government and their partner, Federal University of Rio Grande do Sul, to study flow-induced damage to concrete surfaces. The approach to this study includes an analysis of historical field data and laboratory testing of concrete cavitation damage.

The initial conclusions correlate concrete damage with both concrete strength and the level of air content of the damaging flow over the surface.

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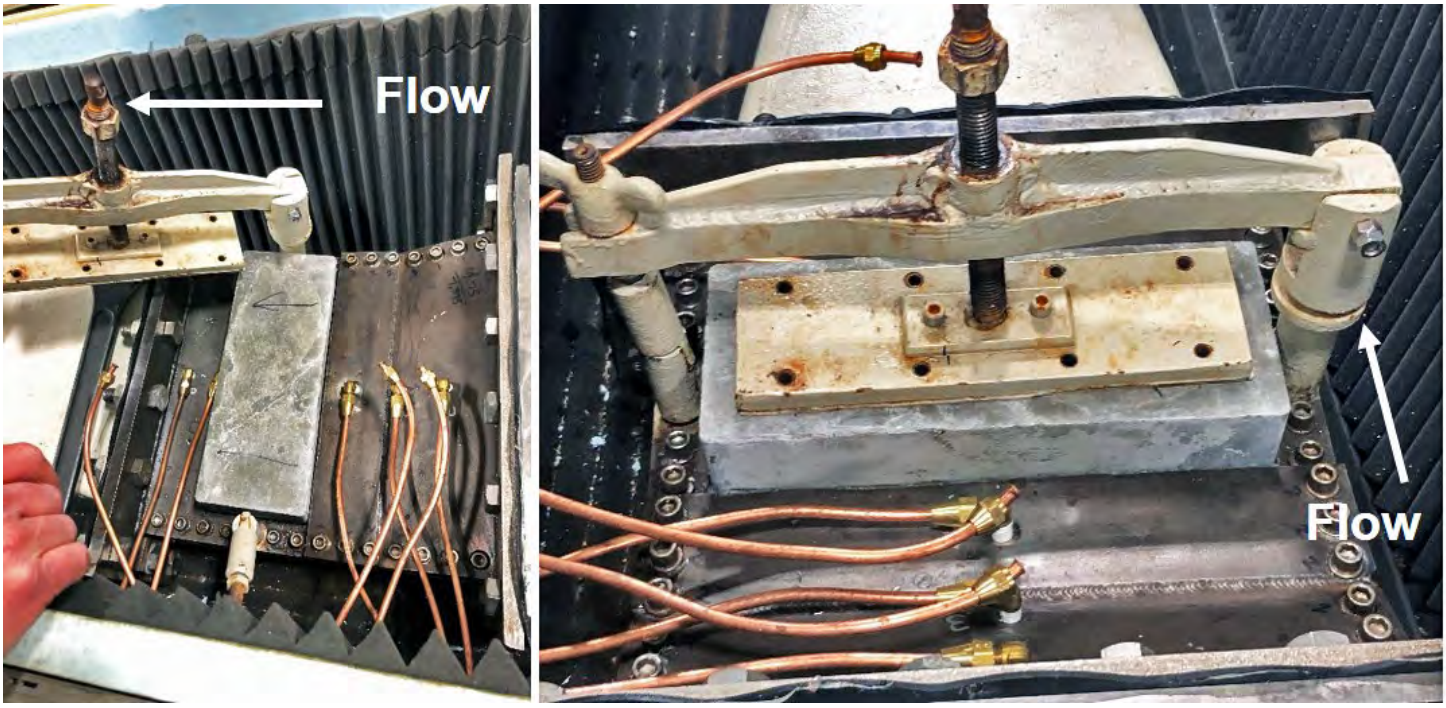
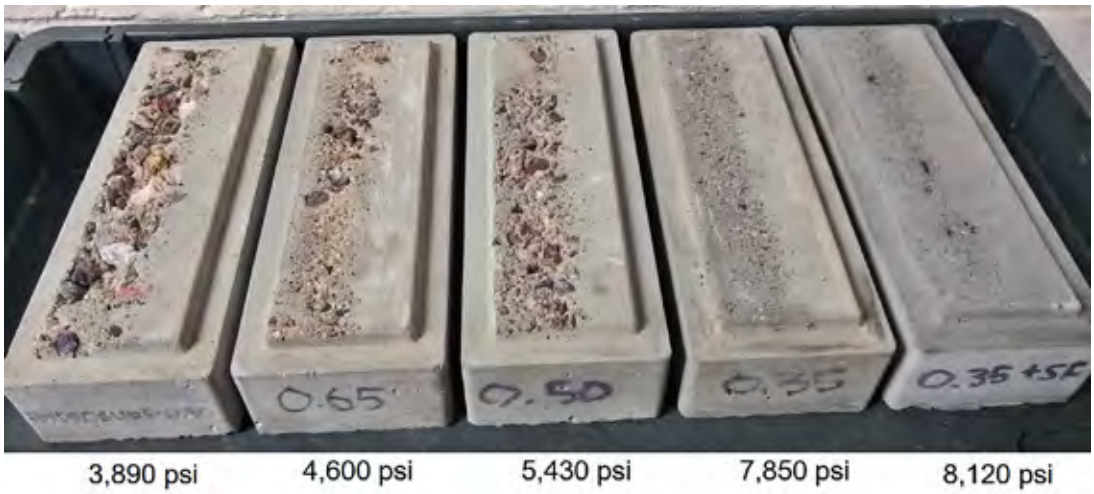


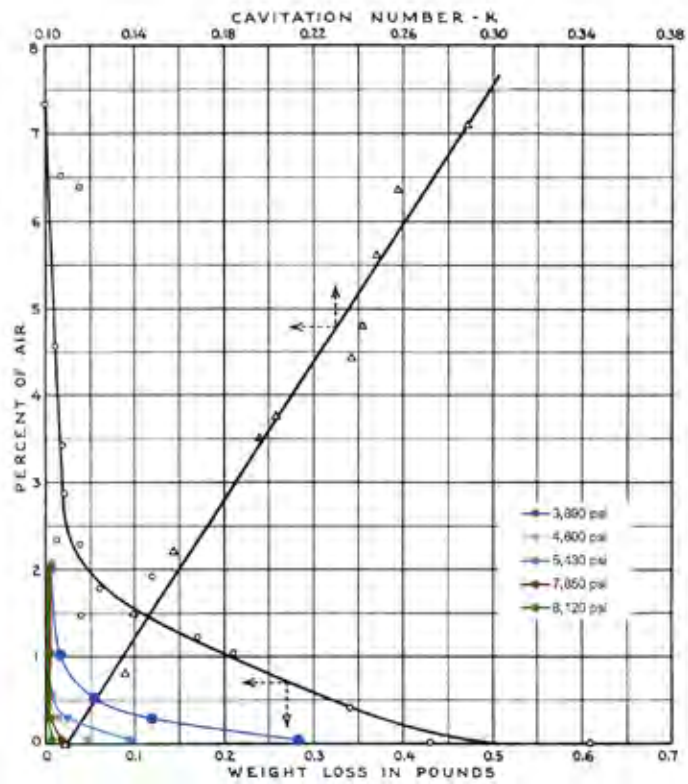
Concrete test sample installed in the cavitation venturi facility in Reclamation's Hydraulics Laboratory.



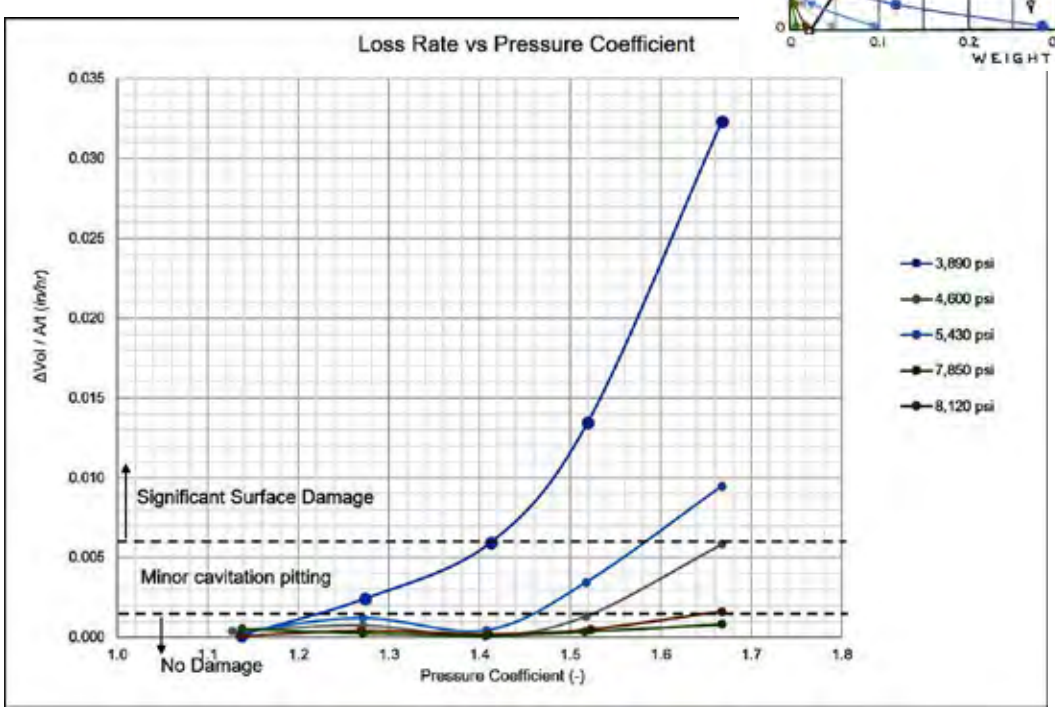
Photograph of concrete damage incurred by 5 different concrete strengths over a 4-hour exposure time in the cavitation venturi. Flow across concrete surface is from left to right.

—continued

Results provide a method to estimate the extent of concrete surface damage in the field based on concrete strength and a pressure coefficient describing localized hydraulics. These results are limited to a single operating condition with intense cavitation (typical cavitation index of 0.06) that may not yet be applicable to other conditions. Additional test results and conclusions are expected from the Brazilian hydraulics laboratory in late 2022.



Comparison of current concrete damage results to a similar study in 1953 (Peterka, 1953). The current study extends results to concrete strengths above 8,000 psi and air content levels down to 0.25%.



Resulting correlation of concrete loss rate (extent of damage) to a pressure coefficient which indicates the level of hydraulic intensity at the surface.

New Cement Materials for Concrete

By Catherine Lucero
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Concrete is made up of gravel, sand, cement powder, and water. In addition to cement, other reactive powder materials, called supplementary cementitious materials (SCMs), can also be used to increase strength and durability. Most concrete contains some type of SCM because it is generally less expensive than cement. In addition, SCMs can enhance fresh properties, e.g., for workability during construction, or increase the long-term durability of the concrete by reducing susceptibility to deterioration by alkali-silica reaction (ASR) or sulfate attack.

SCMs are silica-containing (siliceous) or aluminum- and silica-containing (aluminosiliceous) materials. They can be naturally occurring, such as pumice, or waste materials from other industries. The most used SCM is fly ash, which is a byproduct of coal combustion powerplants. Fly ash is a popular option because it can produce durable concrete while decreasing concrete production costs and lowering the total carbon footprint. As energy policies change, coal burning powerplants have been retired or decommissioned, reducing the supply of fly ash for use in concrete. Concrete producers may face challenges in obtaining a steady supply of fly ash during construction.

Researchers are reviewing alternative SCMs to make up for the short supply of fly ash. The most promising alternatives would need to be produced in large quantities and meet ASTM International, formerly known as American Society for Testing and Materials, standards. One such source is recycled ground glass. When ground to a very fine particle size, it meets chemical and physical requirements of ASTM C618. Glass recycled from the manufacture of fiberglass reinforcement has been shown to mitigate ASR expansion similarly to fly ash. There is also a new specification, ASTM C1866, specifically for ground glass used as an SCM in concrete so the material can be specified for projects.

Another source of SCMs is fly ash that has been previously disposed of in landfills and ponds. For years, large supplies of fly ash were disposed. Research demonstrated that it can be recovered and processed to meet the ASTM C618 specification. In the end, it performs the same as "new" fly ash. Like fly ash direct from the powerplant, the harvested fly ash also has variability. These new commercially available sources can help ease strain on the market when coal plants go offline or are decommissioned in the future.

Brunner Island Power Plant is one example of a large coal ash producer that has reduced coal burning activity as it phases out from coal-fired to natural gas. Photo courtesy of Separation Technologies, Inc.

A sample of harvested fly ash from Brunner Island Power Plant.

Concrete Repair Material Performance for Alkali-Silica Reaction Affected Concrete

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Many concrete structures owned or serviced by Reclamation have experienced deterioration in the form of an alkali-silica reaction (ASR). This reaction occurs within concrete between certain aggregate (rock and sand) and cement. When moisture is available, an expansive reaction between the cement and aggregate occurs that leads to cracking and deterioration throughout the concrete. This damage can be extensive or minor depending on the resources available to fuel the reaction. In extreme cases, concrete may need to be removed and replaced entirely. In some scenarios, a concrete repair is possible, but the repaired surface must be sound and well cleaned, and the repair material must be chemically compatible.

Several bond testing samples prepared for testing.

The Concrete and Structural Laboratory at the TSC is researching various packaged concrete repair materials to determine which material has the best chemical compatibility with concrete damaged by ASR. To do this, concrete slabs (substrates) were created in the lab with reactive aggregate to develop similar characteristics to ASR damaged concrete. The slabs were then overlaid with two packaged repair materials and two concrete mixtures created in the laboratory. Coring and pull-off testing were performed on the slabs to determine the bond strength at the interface between the materials. This process was repeated with control slabs in which the concrete substrate was made with non-reactive aggregate to simulate undamaged concrete. Additional samples were cored and sent to another lab to take a closer look at the interface microscopically.


Bond testing device used to perform bond testing on concrete overlay.

The experiment revealed some interesting interactions. The repair materials created in the laboratory had the highest initial bond capacity. Though one packaged repair material was comparable to the laboratory materials, the other packaged repair material had very low performance. Valuable data was collected from testing, but future testing is recommended to look at more packaged repair products and provide a longer development time for the ASR reaction. Additional time will allow the reaction to progress to a state of greater deterioration, and with further testing, a clearer distinction can be made between available repair materials and concrete developed within the laboratory or in the field.

Rollable Concrete Mats for Reducing Seepage

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Geosynthetic Cementious Composite Mats (GCCMs) are a cement impregnated geosynthetic composite material used in numerous applications. Two applications of interest to Reclamation are lining an unlined canal for seepage reduction and repairing corroded corrugated metal pipe (CMP). The ease of installation for this concrete-based material makes it a desirable solution for reducing seepage of an unlined canal because it can be installed in small canals using a small crew without having to involve a contractor or heavy equipment. The material is supplied in rolls that can be cut into the desired strip lengths with a box cutter. Once fastened into place, it is sprayed with water to hydrate the cement inside the geosynthetic. The hydration process will create a hardened surface that will protect the canal from seepage losses.

Potential Site identified for the demonstration.

Example of a completed lining project using a GCCM. (picture courtesy of Concrete Canvas)

GCCM used for repair of a corrugated metal pipe in Jefferson County, Colorado.

The rollable concrete product can be used in a similar manner to repair CMP, which is most often to repair an invert that has been lost to corrosive conditions. A water district near Denver, Colorado, used it to repair their CMP under roadways and has seen little to no deterioration after 5 years of installation.

Reclamation's Concrete and Structural Laboratory Group is conducting a field demonstration of a GCCM to reduce seepage from an unlined canal. The team will determine the seepage rates of an unlined canal and then install the material at the end of the delivery season. Seepage testing will continue over the next 2 years to determine if it adequately reduced the seepage. The team will return to the site at the end of the 2-year period to evaluate the condition of the material.

Concrete Pipe Sample for Inspection Training

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Some of the largest diameter pipes used by Reclamation are a type of pipe called prestressed concrete cylinder pipe (PCCP). These pipes can be up to 24 feet in diameter and can carry massive amounts of water from one place to another. Some of the PCCP used by Reclamation has been in use for up to 60 years without problems, while others have since failed. Fortunately, failures aren't very common, but when they do happen, they can be very dangerous because of the large pipe size and the amount of water being carried.

To keep failures from happening, Reclamation performs regular inspections of PCCPs to assess the probability of failure and to determine if they need to be repaired or replaced. There are several techniques that can be used for PCCP inspection; however, some are more informative than others, and access to the pipe often limits the techniques that can be used.

To understand how well different inspection techniques work, researchers are studying damaged sections of PCCP and comparing the results to inspection findings. In addition, they are repurposing excavated pipe sections as an educational tool for training Reclamation staff. For example, two sections of PCCP were installed outside the laboratories at the Denver Federal Center. These sections of PCCP were provided by Tarrant Regional Water District after discovering a large amount of damage during inspection and then removing them from service. Walkways were installed around the outside of the pipe to give students access to different areas of the pipes for a hands-on demonstration of different inspection techniques. The pipe sections will next be undergoing a forensic analysis to compare the results against the initial inspection findings. For the educational portion of this study, a curriculum will be developed that includes classroom materials, hands-on tasks, and the use of inspection tools. Support for this activity was provided by Reclamation's Asset Management Division.

PCCP sections being installed at the Denver Federal Center.

PCCP sections after installation.

PCCP demonstration setup with walkways.

Metal & Alternative Materials

New Rope Materials for Large Equipment

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Traditional wire ropes hoisting radial gate.

Wire ropes provide hoisting and positioning for gates, cranes, and similar Reclamation equipment. The typical materials for wire ropes are galvanized steel or stainless steel wires. Corrosion is a serious issue for galvanized steel, and it can lead to a catastrophic failure. Because the wire rope is used in gate hoists to control discharge, as well as in cranes to lift heavy, plant equipment, this can cause significant damage to the equipment as well as to surrounding populations if flooding results. Stainless steel is less susceptible to corrosion, but it is very expensive and often cost prohibitive.

Kevlar rope is being evaluated as a possible alternative to traditional wire rope materials. The benefit of Kevlar rope is that it does not corrode as quickly as steel. This would increase the service life of ropes at Reclamation facilities, saving money through less frequent rope replacement. The strength of Kevlar rope is also a potential benefit because larger rope requires a larger drum to spool the rope on, and therefore larger corresponding in-line equipment. If Kevlar is a stronger material than steel, this decreases rope diameter and the size and ratings of the remaining equipment, reducing the overall footprint.

Close-up of traditional wire rope containing broken strands.

This research will help determine if Kevlar is a suitable replacement rope material and its appropriate applications. Little data is currently available for Kevlar ropes. For example, when choosing a steel rope for an application, there is a chart of wire size versus breaking strength that makes selection easy. For Kevlar rope, manufacturers provide rope data and rope designs on a case-by-case basis for specific application. The available sizing charts only cover a small range of the rope sizes and capacities used across Reclamation facilities. This research is needed to verify material properties so Kevlar rope can be used with confidence.

Testing 3D-Printed Metal Parts

By Dave Tordonato, Stephanie Prochaska, Matt Jermyn, & Grace Weber; Partner: CGB, LCB, and CPN Regions & Oak Ridge National Laboratory
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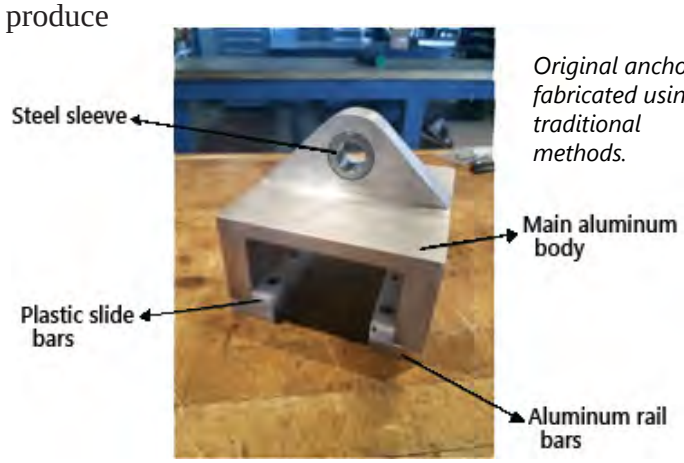
Additive manufacturing (AM), sometimes referred to as "3D printing," is an exciting technology that allows designers to create (print) parts directly from a computer file. Typical 3D printing materials are plastics and metal. Metal printing is increasing in popularity and uses wire or powder as the input material. By contrast, traditional fabrication entails machining a metal block or sheet and is a "subtractive" process. A subtractive process typically requires multiple steps, but it becomes more economical for mass production.

A cube 3D-printed from stainless steel using a powder bed fusion AM process. Note that the angle of the cube relative to the build plate was selected to minimize warping from thermal stresses.

Due to the age of many Reclamation structures, replacement components may no longer be mass produced or even available. AM offers a potential alternative to expensive custom fabrication and long lead times. AM also provides for new or more efficient designs that would be difficult or impossible to produce with traditional manufacturing techniques.

While AM offers advantages over traditional fabrication, it is not a universal solution. The mechanical properties of 3D-printed metals—such as tensile strength, ductility, or hardness—may not match those of traditionally fabricated materials. Also, AM parts may be more expensive to produce than a custom-machined part. The current research project is testing 3D metal parts to see if the mechanical properties are strong enough for use at Reclamation. To test the parts, cubes were printed using several AM techniques (top image), test specimens were cut from the cubes, and then the specimens were tested destructively to determine the best AM technique for each application.



Original anchor fabricated using traditional methods.

In partnership with Oak Ridge National Laboratory, Reclamation is looking at three case studies—an anchor block, a governor part, and a slinger ring—to see if these parts can be made faster or cheaper with AM. Researchers are also looking to take advantage of the complex shapes that can be produced with AM to improve the end product, such as by reducing the weight or the number of parts in a component (middle and bottom image). The goal of this project is to better understand the limitations and best-use case scenarios of AM to allow Reclamation to take advantage of this evolving technology.

Anchor 3D-printed from aluminum using a powder bed fusion AM process. The additively manufactured anchor was redesigned to reduce material while maintaining the necessary strength.

Coating & Repair Materials

New Materials for Repairing Turbine Runners

By Chrissy Henderson, Ph.D. & Allen Skaja, Ph.D.; Partners: U.S. Army Corps of Engineers, Naval Research Lab, & NCP Coatings
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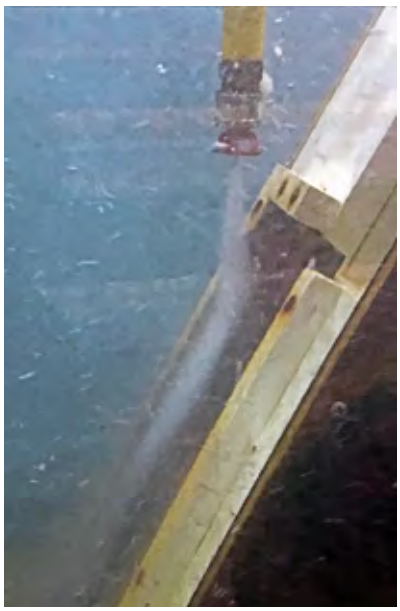
Turbine runner damage from cavitation.

Reclamation structures are designed to handle high pressures and fast flowing water to generate power and distribute water. The highest performance components of these structures, the turbine runners, experience conditions that cause microimpact damage from a phenomenon called cavitation. The unique conditions generally result in localized damage. If not repaired quickly, advanced cavitation damage will require the structure to be taken out of service.

Cavitation occurs at locations in the water flow where there is a sudden pressure change. This condition causes vapor bubbles to form in the water. Once formed, the vapor bubbles implode with an impact force so great that it can damage metals and concrete.

Accumulated cavitation damage causes high-cost maintenance issues. For example, at Grand Coulee, repairing a turbine runner damaged by cavitation can cost $1 million per unit using stainless steel weld overlays, and the downtime can cost upwards of $500,000 per day the unit is not operating. Improved cavitation repair materials can extend the time between these costly repairs and provide significant cost savings.

Elastomeric coated sample result after cavitation testing at 3.5 gallons/min for 32 hours (40 hours before damage to base metal is the pass/fail criteria).



Cavitation submerged water jet test set-up.

Finding materials or processes that can offer cavitation resistance in Reclamation service conditions is a challenging task. Current cavitation repair methods involve using a stainless steel weld overlay on the damaged sections of turbine runners. When paired with steel turbine runners, the stainless steel weld overlay causes galvanic corrosion that corrodes the underlying steel runner. As galvanic corrosion occurs, the weld overlay loses bond strength with the steel base metal of the turbine runner.

Phase I of this research established a cavitation/erosion testing methodology to test different material samples, including cold spray stainless steel, thermal spray nickel alloys, and baseline metals. Phase II of this research involved testing various coatings that may provide cavitation resistance. Researchers identified an elastomeric coating that could extend the life of a stainless steel weld overlay. The results of this research have fostered new collaborations with coating partners to establish viable cavitation/erosion resistant repair options and combinations.

New Coatings for Protecting Structures

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Historical coatings and linings used on Reclamation infrastructure provided more than a 50-year service lifetime. Modern coating systems provide a reduced service lifetime, nearer to 15–30 years. The U.S. Army Corps of Engineers and Reclamation are studying historic vinyl coatings to better understand what properties provided long-term corrosion protection. Further, the research identified several modern coatings that have similar properties.

Radial gates at Fontana Dam that are coated with a polysiloxane coating system.

Polysiloxanes from five different coating manufacturers were tested side by side with vinyl coatings in laboratory testing to compare their corrosion protection and mechanical properties. The epoxy polysiloxanes were compared using epoxy primers, zinc phosphate inhibitive primers, zinc rich primers, and direct to metal, i.e., no primer. Epoxy polysiloxane coatings were designed for atmospheric service environments. Manufacturers do not state water immersion as a service environment, but laboratory testing at Reclamation showed that polysiloxanes from multiple manufacturers had excellent corrosion protection in water immersion.

Laboratory testing results for polysiloxanes with various epoxy primers showed that two manufacturers had similar performance to vinyl coatings in immersion testing, barrier properties, and all accelerated weathering and cyclic testing. However, some of the mechanical properties such as impact, erosion, and abrasion resistance had much poorer performance than vinyl. The research showed that some epoxy polysiloxane coatings may be suitable for use in immersion and fluctuating immersion service if the service environment does not have moderate erosion, high impact forces from debris, or abrasion forces from mechanical equipment; vinyl is still recommended in these service environments.

Vinyl test panels after cyclic testing showing corrosion damage at the scribe (left) before and (right) after removing loose coating.

Polysiloxane test panels after cyclic testing showing corrosion damage at the scribe (left) before and (right) after removing loose coating.

The Tennessee Valley Authority applied an epoxy polysiloxane to four radial gate structures at Fontana Dam in 2015 and 2016. In fall 2019, Reclamation researchers were able to inspect the gates and found them to be in excellent condition, with exceptional barrier properties. The only defects observed were believed to be caused by application error.

Studying Coating Additives that Prevent Corrosion

By Stephanie Prochaska, Allen Skaja, & Carter Gulsvig
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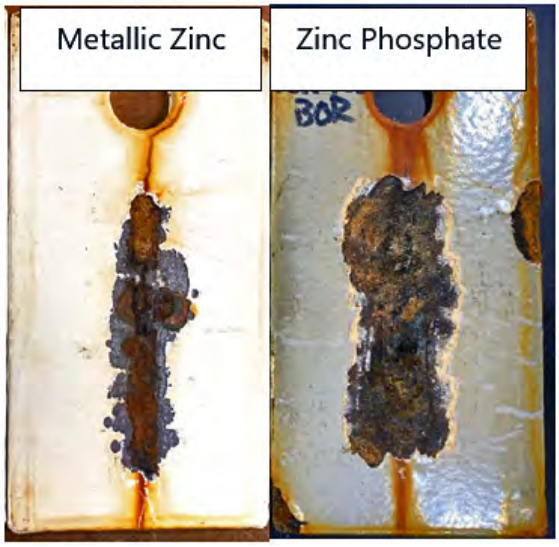
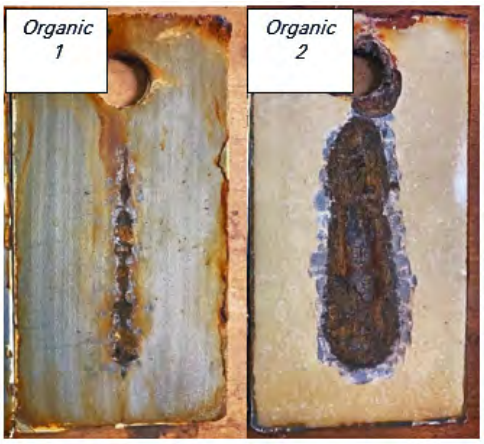
Coating systems currently used to protect Reclamation's aging infrastructure are only expected to last 20–30 years before they need to be replaced. Maintaining and recoating Reclamation's coated structures costs millions of dollars every year, not including money lost from the infrastructure being unusable while being recoated. Some of the first and oldest coating systems used by Reclamation, like lead-based alkyds, have lasted upwards of 80 years.

Lead-based alkyds, a type of coating called an inhibitor coating, contains an additive that actively prevents corrosion (rust) by stopping one or more parts of the process that forms rust. Many previously used additives can't be used anymore because of environmental and health impacts. On the other hand, barrier coatings, the type of coating that is used most by Reclamation, prevent rust by being a barrier between the rust-causing liquids and the metal infrastructure. The goal of this project was to test modern coatings with different additives to see if they work as well as coatings used in the past to protect Reclamation's infrastructure against rust.

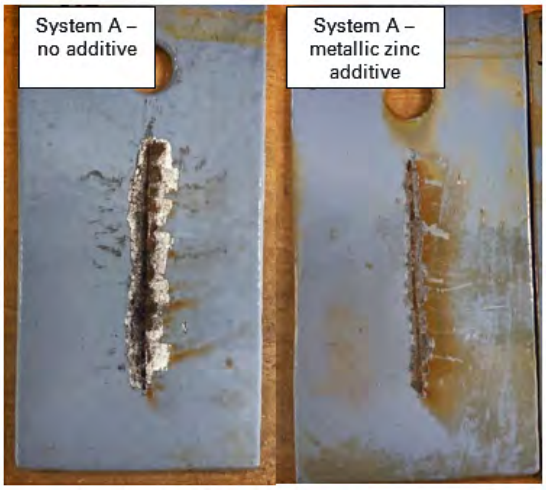
A previous Reclamation study found that three different additives are most common in inhibitor coating systems: metallic zinc, zinc phosphate, and organic additives. The current work tested commercially available and experimental coatings that contain those rust-preventing additives. Researchers used accelerated weathering and other tests to evaluate coating performance. One coating system with a metallic zinc additive performed similar to the vinyl system that had the properties researchers were trying to match. In addition, the metallic zinc inhibitor system can be applied in two layers, compared to the vinyl system, which is five or more layers. Testing for a longer period is needed to confirm the results, but this study showed that some newer coating systems perform as well as long-lasting, older ones.



Compared to the coating system with the zinc phosphate additive, the metallic zinc additive had significantly less corrosion undercutting after the same evaluation period.



Coating systems with the organic inhibitor additives had different amounts of corrosion undercutting.



The metallic zinc additive prevented corrosion undercutting compared to the same coating system without the additive.

A New Technique for Coating Removal

By Kevin Kelly, Stephanie Prochaska & David Tordonato; Partner: Atmospheric Plasma Solutions
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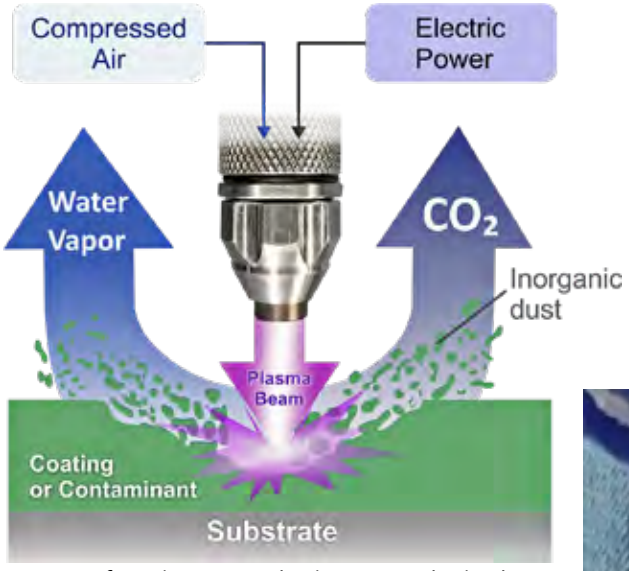
Coatings require periodic removal for repairs, inspections, or reapplication to maintain the integrity and water delivery reliability of Reclamation assets. However, the process for removing old coatings in preparation for applying fresh coatings is largely unchanged for the past 100 years. Removing coatings remains complicated, time consuming, costly, and can be dangerous.

Atmospheric Plasma Solution, Inc. (APS) developed a coatings removal technology that applies plasma at atmospheric pressures. This is sometimes referred to as "cold plasma" because it can operate in the open air without the need of any special chambers and containment.



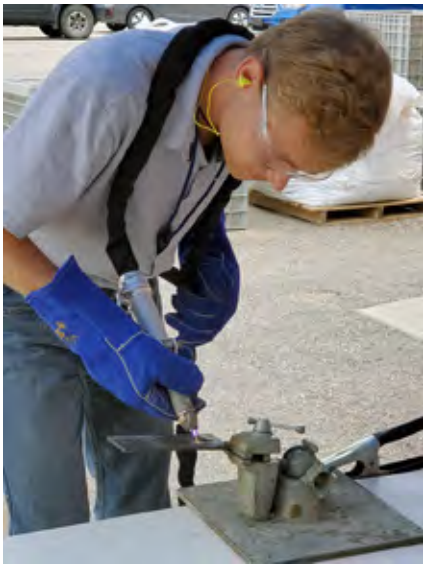
Process of coating removal using atmospheric plasma (credit: APS).

Plasma is a state of matter that is neither solid, liquid, or gas. It is superheated and consists of gaseous ionized atoms or molecules. In fact, it is the most abundant state of matter in the universe. It is commonly found in stars, neon lights, lightning, and the auroras that sometimes ripple over the north and south poles, i.e., the aurora borealis or "northern lights."

APS provides plasma coating removal technology for portable systems, laboratories, and commercial settings. They require a low pressure (70–100 psi) compressed air source and electricity (208–240 volt) to produce the plasma. The plasma generated is highly chemically activated and oxidizes organic components in paints, epoxies, sealants, coal tar, etc. The byproducts are water vapor, carbon dioxide, and a small amount of solids. These inorganic coating pigments and fillers can be safely collected by high-efficiency particulate absorption (HEPA) filters. Overall, this coating removal process may be cleaner, environmentally safer, and more cost effective.

Reclamation's Materials and Corrosion Laboratory Group is investigating the effectiveness and applicability of the APS technology for coating removal. Researchers are determining its usefulness in the replacement of aging coatings in Reclamation facilities, hazardous waste minimization during coating removal, and the economics of this process versus conventional coating removal processes. Collaboration between Reclamation and APS is ongoing to understand potential uses. The goal is to identify an improved process for the removal of existing coatings and surface preparation of steel structures in Reclamation facilities.

Close up view of plasma with "shock diamonds" on a small panel coated with coal tar enamel.



A student intern practicing using atmospheric plasma to remove coal tar coating on a small panel.

Studying & Testing Rock & Soils

Studying Internal Erosion of Soils in the Lab

By Carolyne Bocovich & Robert Rinehart
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Testing apparatus (rigid cell permeameter) with loaded soil specimen, pore pressure transducer, water tanks, and the LabVIEW program used to run the test.

One in four dams in Reclamation's inventory has experienced an internal erosion incident, which makes internal erosion one of the largest risks to Reclamation dams. Internal erosion is the movement of soils from within a dam embankment or its foundation. This research focuses on one type of internal erosion, internal instability, in which fine soil particles are eroded out of a coarser matrix. The conditions in which a soil is susceptible to internal instability is extensively researched and well defined based on the soil sizes of the fine particles relative to the size of the coarser particles. However, once internal instability occurs, the impact is not well understood. This research focuses on characterizing the result of internal instability if allowed to continue unimpeded.

Reclamation has funded several projects investigating internal erosion, including project 8284, Cracked Embankment Erosion Research. The current research is evaluating the feasibility of using the current equipment at Reclamation. It will also establish preliminary trends. Testing is carried out in a rigid cell permeameter varying soil gradation, mechanical loads, and hydromechanical loads (gradients across the specimen). During the test, the hydraulic gradient and vertical consolidation load are controlled. The flow rate, pore pressure changes across the specimen, and deformation of the specimen are being measured. From these measurements, specific effects of the erosion are analyzed, including the amount of erosion, changes in volume, and changes in permeability. This research will result in preliminary trends between the initial conditions (soil gradation and load) with consequences of erosion (changes in volume and permeability of the soil).

Methods to Disaggregate Rock and Clay Soils

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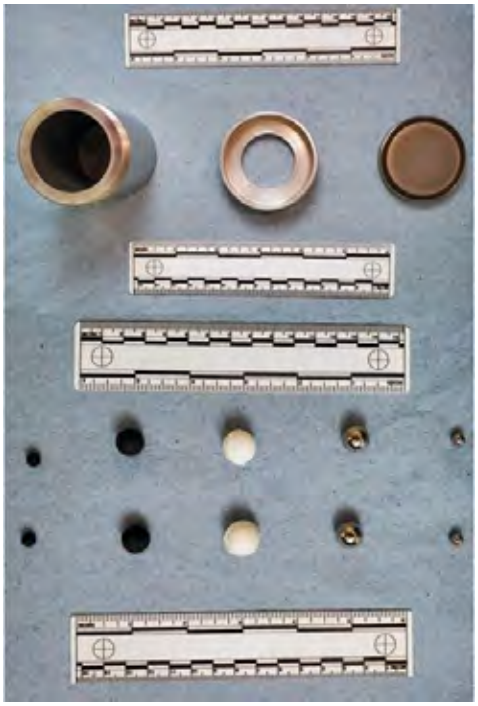
Reclamation has many facilities where the local geology contains rock that breaks down when exposed to water or the atmosphere. This process of breaking down is termed "slaking" and is common for shale or claystone. These types of rock are notoriously difficult to sample and cannot be tested using typical rock-type physical property testing. Many Reclamation sites also contain clayey soil that, when air-dried or desiccated, is difficult to disaggregate (separate) for testing. The clay minerals that make up these rocks and soils are often susceptible to swelling and low shear strength zones in slope stability, which can lead to challenging geotechnical design considerations.

A common practice for slakable rock and desiccated fat clay is to disaggregate it into its constituent clay-size particles for testing. Typical evaluations include residual shear strength, gradation, and Atterberg limit testing. Conventionally, this processing is done by hand (mortar and pestle) and does not fully disaggregate the clay-size particles in the sample. This can lead to overestimating the material's physical and engineering properties. In addition, hand processing is both time consuming and labor intensive. While the current standards are limited to hand processing, the use of a ball mill to fully disaggregate clay minerals is a superior approach that has a well-established background in literature. Compared to hand processing, ball milling is less time and labor intensive, and it is largely an automated process.

Despite the acceptance and use of ball milling, there is no established standard for processing clay and slakable rock via a ball mill. In addition, there has not been significant study of the effects of ball mill variables such as milling duration, ball size, ball material, etc. This research seeks to study the variables associated with ball mill processing on a variety of rock and clay materials obtained from active Reclamation projects. The research will then develop a standardized method to process slakable rock and desiccated clay to be adopted by the TSC and regional geotechnical laboratories.



Sample processing cannister (top) and ball bearings of various size and material (bottom).

Unprocessed rock and soil (top) vs. ball milled rock (bottom).

Ball mill device being used in this research.

Methods to Evaluate Riprap Quality

By Robert Rinehart
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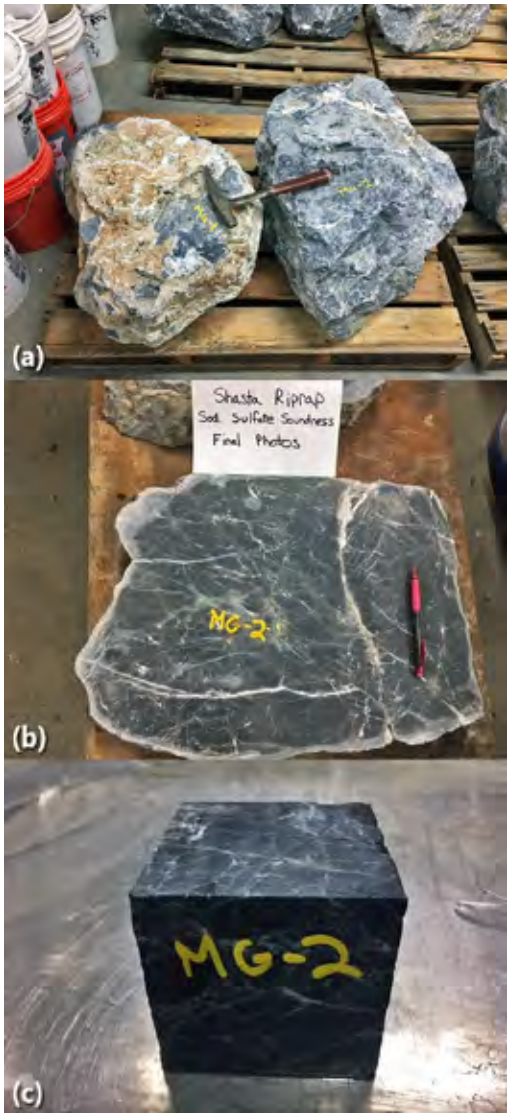
When dealing with water-related infrastructure, soil erosion is often a critical issue for infrastructure longevity. Controlling riverbank migration, preventing scour around bridge pilings, and protecting embankments from wave erosion are things that Reclamation engineers deal with routinely. The various forms of erosion can damage earthen structures and lead to failure if not controlled. There are many methods available to mitigate erosion, with one of the most common and economical methods being the placement of large rocks and boulders–called riprap–where erosion is a concern (see photo on back cover).

To perform as designed, the rocks and boulders that make up riprap must be strong and durable under a variety of loading and climactic conditions. Specifically, they must resist thousands of cycles of wetting and drying, and freezing and thawing, as well as impacts from ice chunks and other floating debris.

During the major dam building phases of Reclamation's history, the demand for large quantities of riprap made onsite quarrying operations feasible. Engineering geologists conducted extensive field investigations, often including test blasts, to evaluate the rocks and boulders available onsite. Expertise and visual observation were heavily relied upon to ensure that riprap was of good quality and would meet the design requirements. Lab testing was performed to confirm the findings of the field investigation. Reclamation's historic methods, and subsequently our construction specifications, grew out of this approach.

Although Reclamation's modern-day riprap needs are significantly less, nearly every project modifying an earthen structure requires some amount of new slope armoring riprap that must be both strong and durable. The idea of developing a new onsite quarry is rarely entertained; instead, purchasing from commercial quarries supplying riprap is a more common alternative. This places more emphasis on lab testing to ensure that material is of suitable quality to last for the design life of the structure. Newer lab test methods have been developed to test larger, more representative slabs of rock instead of the smaller cubes and aggregate-sized material tested used in the historical methods. Research is underway to compare the newer test methods to the traditional methods to ensure that the results of the new tests are understood and an optimized approach can be developed. This will aid in the development of construction specifications to ensure that adequate material quality is maintained when commercial sources are used.



(a) Riprap block (b) 2-1/2-inch-thick freeze-thaw slab specimen used for new testing methods, and (c) 2-7/8-inch cubic freeze-thaw specimen used for traditional testing methods.

Equipment used to prepare riprap test specimens; 42-inch diameter diamond wet saw.

Featured Faces

Catherine Lucero

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Catherine is a civil engineer at Reclamation's Concrete and Structural Laboratory in Denver, Colorado. She received her B.S. in civil engineering at the University of New Mexico and her MS in civil engineering at Purdue University. She has 8 years of experience in concrete testing and research. Her interests include design of mass concrete mixtures, mass concrete construction and the use of supplementary cementitious materials to increase durability. Catherine is active in the American Concrete Institute (formerly National Association of Cement Users) and is currently the President of the Rocky Mountain Chapter.

Richard Bearce

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Rick is a civil engineer who has worked with Reclamation's Geotechnical Laboratory and Field Support group for 5 years. He specializes in rock mechanics, laboratory-scale nondestructive testing, and the development of innovative geotechnical laboratory tests and data analysis tools. Rick's research interests include shear strength behavior of rock and concrete, assessment of abrasion potential in reservoir sediment, and engineering property characterization for weak rock. Rick received his B.S. in Physics and Applied Mathematics from Millikin University and his M.S. and Ph.D. in Geotechnical Engineering from the Colorado School of Mines. Rick is a registered Professional Engineer in the State of Wyoming and is active in both ASTM International and the American Rock Mechanics Association.

Josh Mortensen

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Josh is a hydraulic engineer in the TSC's Hydraulic Investigations and Laboratory Services group. He has 12 years of experience in physical hydraulic modeling, field investigations, and computational fluid dynamics. He has conducted several studies on cavitation, air demand for pipes and penstocks, vibration and fluid-structure interactions, fish passage structures, and various hydraulic structures and equipment. Josh earned a B.S. degree in Mechanical Engineering from Brigham Young University – Idaho and a M.S. degree in Civil Engineering from Utah State University. He is a registered Professional Engineer in the State of Colorado.

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Grace is a materials engineer working out of Reclamation's Materials and Corrosion Laboratory Group, based in Denver, Colorado. She holds a B.S. in Metallurgical and Materials Engineering and an M.S. in Engineering and Technology Management from the Colorado School of Mines. Grace first began with Reclamation as an intern in 2017 and was hired into the Materials and Corrosion Laboratory Group in 2019. Her focus is on corrosion mitigation, including design of galvanic and impressed current cathodic protection systems, research in novel corrosion prevention techniques, and field corrosion inspections and cathodic protection surveys. Grace also provides support to the Science & Technology Program through her involvement in hosting virtual meetings, workshops, and other related activities in the water infrastructure research area.