Research Update

Summer 2015
Bulletin 2015-10

Bottom Line

This scoping-level research project study reviewed existing literature to unlock the secrets of Roman concrete properties and explored the possibility that Reclamation structures might be using a similar type of concrete.

Better, Faster, Cheaper

Manufacturing a more durable concrete and long-lasting concrete, would decrease the amount of concrete repairs and replacement.

When concrete lasts a long time less concrete needs to be produced, decreasing carbon dioxide emissions, thus lessening our impact on the environment. A manufacturing process that produced fewer carbon emissions would further help reduce carbon footprints.

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Taking Cues From the Ancient Romans

Understanding and using the properties that allow Roman concrete to last over 2,000 years

Problem

Reclamation's infrastructure relies on concrete, and its durability and longevity are essential foundations for delivering water and power. While Reclamation's facilities are designed to last a single century, the Romans built with concrete that has lasted well over 20 centuries.

Modern concrete (Portland cement) consists of calcium, silicates, and hydrates (C-S-H) (water molecules that chemically bind to other molecules). This mix of limestone and clay needs to be heated to 1,450 degrees Celsius (2,642 degrees Fahrenheit). Both burning fuels and the heated limestone (calcium carbonate) release carbon dioxide. Portland cement used in concrete accounts for approximately 5 percent of annual anthropogenic carbon dioxide emissions.

In contrast, the Romans made concrete by mixing lime, volcanic rock, and a small amount of water and baking it to a lower temperature (only to 900 degrees Celsius or 1,652 degrees Fahrenheit). The water and lime reacted with the ash to create cement. According to surviving writings of Vitruvius, an engineer for the Emperor Augustus and Pliny the Elder, the best maritime Roman concrete was made with ash from the seaside town of Pozzuoli, Italy. Volcanic ash (or natural pozzolan) with similar mineral characteristics is found in many parts of the world, including the Western United States. Experts (e.g., Jackson et al., 2013) argue that Romans deliberately selected alkali- and alumina-rich ash for optimal performance of pozzolanic concretes. Roman concrete takes longer to cure, but the strength and durability may well compensate for that time.

Solution and Results

This Reclamation Science and Technology Program research project examined previous literature to determine potential avenues for further Reclamation research into ways to adapt Roman concrete techniques.

In theory, hydration of Portland cement resembles a combination of naturally occurring layered minerals including tobermorite. The ideal state would have a regular molecular structure resembling fibers. However, in reality, this ideal crystalline form of tobermorite is rarely found in modern concrete. Instead, tobermorite (C-S-H) occurs as an amorphous gel.

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The cement in Roman concrete contains more aluminum and less silicon than modern concrete, which may be the key to the longevity of Roman concrete. This resulting calcium-aluminum-silicate-hydrate (C-A-S-H) is an exceptionally stable binder. These natural substances formed structures (almost like cages) around sulfide and chloride ions that could cause concrete to deteriorate if these ions were free in the concrete.

Assessing some of Reclamation's structures to determine if they possess some of the properties similar to Roman concrete is also an important next step. Pumice deposits were used in historic concrete constructions in the West; in particular, the San Francisco peaks' pumice used in the construction of Glen Canyon Dam, Arizona. Reclamation's Upper Stillwater Dam, a roller-compacted concrete gravity dam about 31 miles northwest of Duchesne, Utah, might also use concrete with similar properties.

Upper Stillwater Dam, Utah.

Future Plans

Further research is needed to find out how to re-create the durability and low emissions in Roman concrete for future use in Reclamation and other industry concrete practices, including:

- Conducting similar studies that Jackson et al. (2013) conducted on other infrastructure using concrete samples from Reclamations' Upper Stillwater and Glen Canyon Dams (e.g., using a scanning electron microscope and X-ray diffraction) to determine if this concrete forms similar structures to Roman concrete
- Reverse engineering Upper Stillwater Dam construction methods and other Roman concrete manufacturing methods to determine effective ways to promote the growth of crystalline Al-tobermorite in modern concrete
- Developing ways to alter the chemistry (alkali and aluminum content) and physical form (pumaceous clasts) of commercial fly ash to resemble the volcanic ash used in Roman-style concrete
- Determining whether adding aluminum to a concrete mix reduces the chance of alkali-silica reaction
- Identifying sources of alkali- and alumina-rich volcanic ash (natural pozzolans) in the Western United States that might be used to reproduce Roman-style concrete

"Examining these ancient techniques could help improve concrete strength, durability, and longevity while reducing global carbon emissions."

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More information

http://www.usbr.gov/research/projects/detail.cfm?id=7137

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