Government officials, engineers and taxpayers must deal with the challenges of how to go about the repair and restoration of our aging municipal public works infrastructure. Engineers use many modern techniques to overcome aging wear and tear on the great structures that were built 50 or more years ago, in many cases preserving the original structures. The Golden Gate Bridge is a prime example of the challenges of continuing preservation of an iconic structure.

Unique Roman bridges offer clues as to how it was done centuries ago

The aging and repair of monumental municipal structures is not a process that is unique to modern public works engineers. There are many examples left from antiquity that show that ancient Roman civil engineers faced similar challenges throughout the Roman Empire.

Two restoration examples are located in the countryside near Arles, France, where there is an ancient Roman aqueduct system that includes bridges and tunnels. The system has existed for nearly 1,900 years, and its surrounding countryside area is rich in history, including serving as the working grounds for the great artist Vincent van Gogh. The aqueduct bridge system has stood the test of time, surviving earthquakes, wars, floods and the strong Mistral winds of southern France. The bridges were engineered by Romans using the famous arches for a municipal water service, and no doubt constructed at a great expense. The aqueduct bridges, made of stone and concrete, were repaired from time to time.

Two aqueduct bridges, locally known as the Pont...
Simian (Simian Bridge) and the Ponts Vallon des Arcs (Valley of the Arches Bridges), are part of the aqueduct system that initially served the Roman garrison city of Arelate (present-day Arles) with domestic water. The water also served to power water wheels at the historic mill, an important early Roman industrial mill site. The aqueduct brought water from the distant springs in the Alpilles Mountains to the city and mill. The original bridges were built in the first century, with the Simian Bridge being built on mildly sloping hills. It is now on private property and is well out of the way for the normal tourist.

Many of the great ancient aqueducts were in or near populated areas. Some have been lost either by building-block cannibalization or by one urban renewal project after another over the centuries. The original design, construction and subsequent maintenance and repair work on these Roman bridges is often no longer evident. In comparison, the Simian Bridge and Valley of the Arches Bridges are located in more rural agricultural areas and have been protected from the extensive stone and brick cannibalization that occurred on many other Roman bridges. The location of these bridges has helped preserve them, allowing us the privilege to examine evidence of Roman repair and restoration work.

**There are two types**

The Simian Bridge crosses a small valley and is 157 ft long and 15 ft high. It consists of four (originally five) semicircular arches. Each arch has a radius ranging from 4.5 to 8 ft. The fascinating aspect of the Simian Bridge is being able to see two different types of construction on the same structure. These construction types represent an evolution of engineering building techniques that occurred between the original construction of the bridge and the restoration of the structure that occurred a century later.

The original structure was constructed in the first century using grand appurtenance, large limestone blocks that were quarried from the nearby Alpilles Mountains.

Each end of the bridge is connected to the natural slopes of the valley. These were the first sections of the bridge to require reconstruction, since the bridge was less stable at these points. At first look, the structural breakdown appears to be caused by flood flows and erosion due to scour velocities around the abutments. However, we have performed a hydrologic and hydraulic evaluation for the structure and have concluded that the bridge arches should have easily passed the maximum probable storm runoff event from the upstream basin. Water should not have attained a height to overtop the structure or breach the ends.

Therefore, the cause of the bridge’s decay and its need for restoration during antiquity is not entirely clear. Some researchers have concluded that the cycles of freeze and thaw have led to the rupture of the block in lamellate pieces, especially on the upstream and north-facing side of the bridge. However, there is no apparent major cracking in the structure from earth movement, even today. The foundation is on limestone bedrock and is sound. In addition, the streambed is normally dry and any great flood flow in the channel crossed by the bridge would not carry debris much larger than shrubs and gravel.

The first repair of the bridge took place on the east end, although no clues have been discovered to establish a date for this first phase of restoration. The restoration of the western end of the bridge was then accomplished. In a later restoration phase, the bridge arches were reinforced due to the apparent failure of the original limestone blocks in the arches.

The Roman engineers used petit appurtenance to repair and restore the bridge. This approach used an outside layer of small brick and mortar as formwork for an interior core of concrete and rubble. The subsequent repair work on the bridge using the brick and mortar approach is stark when compared with the original bridge construction.

**A parallel place in time**

On the same aqueduct and downstream of the Simian Bridge is the Valley of the Arches Bridges. Here, the ancient Romans designed and constructed two parallel-arched bridges in a north-south alignment. Each bridge complex was approximately 985 ft long and crossed what was then a marshy area.

The exact chronology of original construction and repair and restoration of the two arched bridges that span the Valley of the Arches is not known. There have been interesting studies done on calcium carbonate deposits in the channel that give some rough chronological clues. There are five layers of deposits, each with a different thickness and detritus content. These layers record the length of time the system was operated, demonstrating that different water sources were used, and show that there were stoppages of flow for the construction and
repair of the system. Other clues of when the bridges were constructed and restored are from coins that were recovered from excavations around the north end of the aqueduct bridges.

Based on these studies and observations of construction techniques, it is known that the west bridge was the first to be constructed, and was engineered using grand appurtenant. The grand appurtenant construction of the west bridge is evident today at the site. The westside bridge was used first to bring spring water to the city of Arete for domestic purposes. It is believed that the eastside bridge was constructed after the west bridge in the late first century to bring water to the Barbegal mill. The east bridge was built using petit appurtenant.

It is estimated that the west bridge was renovated in the second or third century. Most of the limestone blocks composing the original construction of the west bridge were replaced with a different building technique. Remnants of the restored west arch bridge show the later petit appurtenant construction. A section of this west bridge renovation on the north end made use of the original limestone block foundations. Eventually even this restored west bridge needed repair work. A section of the west bridge arches is still standing, while the east bridge has fallen down in sections. There is a brick and mortar column that was constructed as a buttress, perhaps to address foundation settlement that occurred on one of the west bridge piers.

Do as the Romans do
Studies will continue to be done on the aqueduct system in southern France in an effort to learn about ancient Roman engineering. The bridges in the Simian Valley and the Valley of the Arches Bridges were vital components of the Barbegal aqueduct system. Like all large public works projects, these bridges required periodic maintenance that varied based on the construction techniques practiced by engineers and builders of the particular era. Roman engineering and restoration construction of these bridges extended the life of the system for a period of use that spanned from 300 to 400 years. Many of the hydrologic, hydraulic and structural engineering techniques that were used by the Roman engineers are still used by civil engineers today, demonstrating that with proper maintenance, a public works structure can be useful for centuries.

Lorenz is president of Wright Water Engineers Inc. (WWE), Denver. Wolfram is an engineering intern for WWE and a student at the Colorado School of Mines.