Wine Caves Beneath the Northern California Vineyards

By Scott W. Lewis and William D. Leech

Wine caves are an integral component of the northern California wine industry, with an estimated 130 to 150 caves currently in use for wine aging, barrel storage, tasting rooms and marketing events. The design and construction of wine caves represents a unique application of underground construction techniques.

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High humidity serves to minimize evaporation. Wine makers consider that humidity of over 75 percent for reds and over 85 percent for whites as ideal for wine aging and barrel storage. Humidity in wine caves ranges naturally from 70 to 90 percent.

In northern California, wine barrel evaporation in a surface warehouse is on the order of 4 gallons (15.1 liters) per each 60 gallon (227 liter) barrel per year. In a wine cave, barrel evaporation is reduced to about 1 gallon (3.8 liters) per barrel per year.

Since red wines are usually barreled and aged for two years, this represents a 10 percent gross volume loss difference. For white wines, which are barreled and aged for about one year, a 5 percent loss difference is realized. This is a significant savings for the wine makers.

The wine industry has long considered that a constant temperature between 55°F and 60°F (13.0?C and 15.5°C) is optimum for the storage and aging of wine. The mean annual temperatures in northern California result in a uniform underground temperature of about 58°F (14.5°C), optimum for wine caves. With a surface warehouse comes the energy-consuming requirement to cool, heat and humidify. While the most basic wine cave can cost in excess of $100 per sq ft to construct, lower energy costs result in a net savings over the mid- and long-term.

In the Napa-Sonoma wine-growing region, as in many areas of California, land values are at a premium. Non-agricultural development is often restricted. A storage warehouse reduces the land available to grow grapes, impacts open space and natural habitats, and precludes other land uses. Land-use regulation in California places strict limitations on the types and locations of land development. Many land use restrictions and permitting requirements do not apply to underground space.

Marketing is an important component of the modern wine industry, and many caves serve varied marketing and public relations functions. Recently constructed caves contain commercial and private kitchens, wine-tasting and dining rooms, sales rooms, wine libraries, concert and exhibit halls, staff offices, elevators, restrooms and other amenities. Some have high-end interiors, including ceramic and stone flooring, masonry-lined walls and ceilings, sculpture and artwork, mood lighting, fountains, waterfalls and chandeliers. At Stag's Leap Wine Cellars, a Foucault pendulum swings continuously across a bed of black sand in the central exhibit hall.

The history of wine cave construction in the United States dates back to the 1870s in the Napa Valley region. Jacob Schram, a German immigrant and barber, founded Schramsberg Vineyards near Calistoga in 1862. Eight years later, Schram found a new job for the Chinese laborers who had recently finished digging and blasting tunnels and grades over the Sierra Nevada Mountains for the Union Pacific Transcontinental Railroad. He hired them to dig a network of caves through the soft Sonoma Volcanics Formation rock underlying his vineyard.

Another Chinese workforce took time away from their regular vineyard work to excavate a labyrinth of wine-aging caves beneath the Beringer Vineyards near St. Helena. These caves exceeded 1,200 ft (365 m) in length, with interior dimensions of 17 ft (5 m) in width and 7 ft (2 m) in height. In those days, the Chinese workers used pick-axes and shovels — and on the rare occasion, chisel steel, double jacks and black powder — to break the soft rock. They worked by candlelight, and removed the excavated material by hand, in wicker baskets. At least 12 wine storage caves were constructed by these methods.

From the late 1800s to the early 1970s, the development of wine caves went through a long period of "dark ages." No new caves were built and many existing caves were abandoned or fell into disrepair. A "renaissance" of cave building began in 1972, when Alf Burtleson Construction started the rehabilitation of the old Beringer wine caves. This was soon followed by the design and construction of new caves.

In 1981, the Far Niente Winery completed the first of these "new age" wine caves in the Napa Valley. The cave was only 60 ft (18 m) long and was used exclusively to age the wine and to store empty barrels. In 1991, 1995 and 2001, the caves were expanded with ambition. New rooms and storage areas were added, featuring different crown heights and intriguing shapes. An octagonal room was constructed for a wine library and a round-domed room was added in the complex's center. Far Niente Winery caves now encompass about 40,000 sq ft (3,700 sq m).

In 1991, Condor Earth Technologies Inc. joined with Alf Burtleson on the design and construction of the elaborate Jarvis Wine Cave project. Over 45,000 sq ft (4,200 sq m) of underground winery and cave space was constructed, with cave spans exceeding 85 ft (25.5 m) in width. At Jarvis, the entire winery is contained within the tunneled areas, including crushing, fermentation, barrel storage, bottling, lab, office, marketing and hospitality areas. These caves are open for public tours, by appointment only.

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It can be difficult to find optimal locations for the siting of wine caves in northern California. Much of the ground in the Napa-Sonoma areas is weathered, decomposed, faulted and jointed rock with variable amounts of soil overburden. The challenge for the design and construction of most wine caves is to create a fairly wide span in weak rock with low cover. The size of a typical wine barrel storage cave is 13 to 18 ft (4 to 5.5 m) wide and 10 to 13 ft (3 to 4 m) high. Constructed caves, however, range up to 85 ft (30 m) in width and 50 ft (15 m) in height; difficult to achieve in poor quality rock.

In areas of complex geology, good portal sites are hard to find. A typical wine cave is constructed with two or more portal sites, for safety and operational reasons. At least one portal leads directly outside, but in many cases at least one portal makes a direct connection to a winery building.

Most portals into the wine caves have rock/soil overburden heights less than 0.2 times their entrance heights and widths. The height of the portal face normally ranges from 12 to 20 ft (3.5 to 6 m). The portal areas are seldom stripped of the loose soil material and the portals are cut from the native ground surface using excavators. The side slopes of the portal are often laid back to 0.5H:1V or steeper; and the portal face is excavated to vertical or near vertical.

The construction of cave interiors can be complicated by the elaborate curves and labyrinth-style floor plans selected by some owners for their wine caves. As the ground surface slopes upward, providing more cover and usually sounder rock, caves can accommodate multiple drifts. Where possible, the cave is designed and constructed to provide intersections at least 1.2 times their width of cover at intersections. Room and pillar layouts, reminiscent to underground mine design, provide an economical construction arrangement. Tunnel legs are usually 30 to 100 ft (9 to 30 m) in length and pillars are typically a minimum of 20 ft (6 m) wide.

On most occasions, the New Austrian Tunneling Method (single or multiple face), also known now as Sequential Excavation Method (SEM), with minor innovative technology advances, is used to excavate and support wine caves.

The caves are typically excavated in an inverted horseshoe shape with a crown radius and with straight or curved legs. The tunnels are usually excavated using a tunnel roadheader or a milling head attachment on an excavator. The spoils behind the roadheader conveyor belt are dumped on the invert and mucked out using a rubber-tired skid loader or a load-haul-dump (LHD) mining machine.

Initially, the excavation advance is likely to be limited to 2 ft (0.6 m) without initial ground support. Once turned under, and depending on ground conditions, the unsupported advance may be increased to 4 ft (1.2 m), 6 ft (1.8 m), and longer increments. The maximum advance without initial ground support may reach 20 ft (6 m) or more in stable volcanic ash tuff. In sheared serpentinite, deeply weathered lava rock or wet clayey ground, however, unstable ground conditions may limit the unsupported advance to less than 2 ft (0.6 m).

Shotcrete reinforcement and ground support is utilized at the tunnel portals and in the interior of the wine caves. At the portals, soil nail and shotcrete walls are typically used for permanent support and are constructed from the top down in lifts. Soil nails are installed on 4- to 6-ft (1.2 to 1.8 m) centers in both the horizontal and vertical directions. The shotcrete is typically a minimum of 6-in. (15 cm) thick and reinforced with welded wire fabric. The typical 4,000 psi (28 MPa) design strength shotcrete mix is applied using the wet process.

Within the caves, the initial ground support usually consists of fiber-reinforced shotcrete. A minimum of 2-in. (5 cm) thickness of wet mix shotcrete is applied around the exposed ground perimeter following each day's advance. As cave dimensions and ground conditions require, additional layers of shotcrete and welded wire fabric follow on subsequent days. The shotcrete mix is a 4,000 psi (28 MPa) compressive strength design. In some cases, pattern or spot rock bolts are also installed. Where wider and taller halls are used, modeling is employed to assist with the liner design.

Interior finishing of the caves is an integral part of the construction process. Waterproofing details are an important consideration for the interiors of wine caves. Wet spots and water seeps are unsightly, and can cause maintenance and safety problems. Moisture vapor migration through the cave liner, however, is desirable to maintain humidity.

Most contractors install prefabricated drainage strips at regular intervals between the native ground and the shotcrete liner. The drain strips relieve the hydrostatic pressure, but have little effect on wet spots and water seeps. Xypex® has been used for many years to mitigate seepage, either as a shotcrete admixture or spray applied, with relatively good success. Where excessive groundwater is present, however, membranes placed between successive shotcrete layers have been used. Many new products, including admixtures and membranes, are being evaluated and tested to improve moisture conditions. The wine cave industry in northern California is at the forefront of waterproofing technology implementation.

After the cave complex has been completely excavated, waterproofed and initially supported, a 2-in. (5 cm) thickness of final shotcrete or plain/colored gunite is applied to the walls and arch. Utility conduits, and piping are encased within the final layer of shotcrete in the walls and arch, and placed under the concrete floor slab. Reinforced concrete slabs are usually 6-in. (15 cm) thick and are underlain by subdrain.

In order to support their varied uses, wine cave complexes may contain as many as 13 different utility systems. These include systems for hot and cold domestic water and processing water; electric power systems for processing equipment, lighting, sound and water features; battery emergency power; compressed gas systems; communications and radio relays; automatic ventilation; and computerized sensors and climate controls.

Condor Earth Technologies

Condor Earth Technologies Inc. is a diversified, multidisciplinary engineering firm with the capability to provide for private and public sector clients' earth and environmental technology needs. Condor's experience includes tunnel and slope conditions evaluations, tunnel portal and liner design, geotechnical foundation and ground support engineering, and surface and underground construction management.

The firm also provides construction materials testing, geographical information systems, real-time position monitoring (3D TrackerTM), survey and mapping (PenMap®), environmental monitoring, and planning and permitting services. Contact Scott Lewis, Condor Earth Technologies, Inc., Sonora, CA 95370, (209) 532-0361, *www.condorearth.com*.

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